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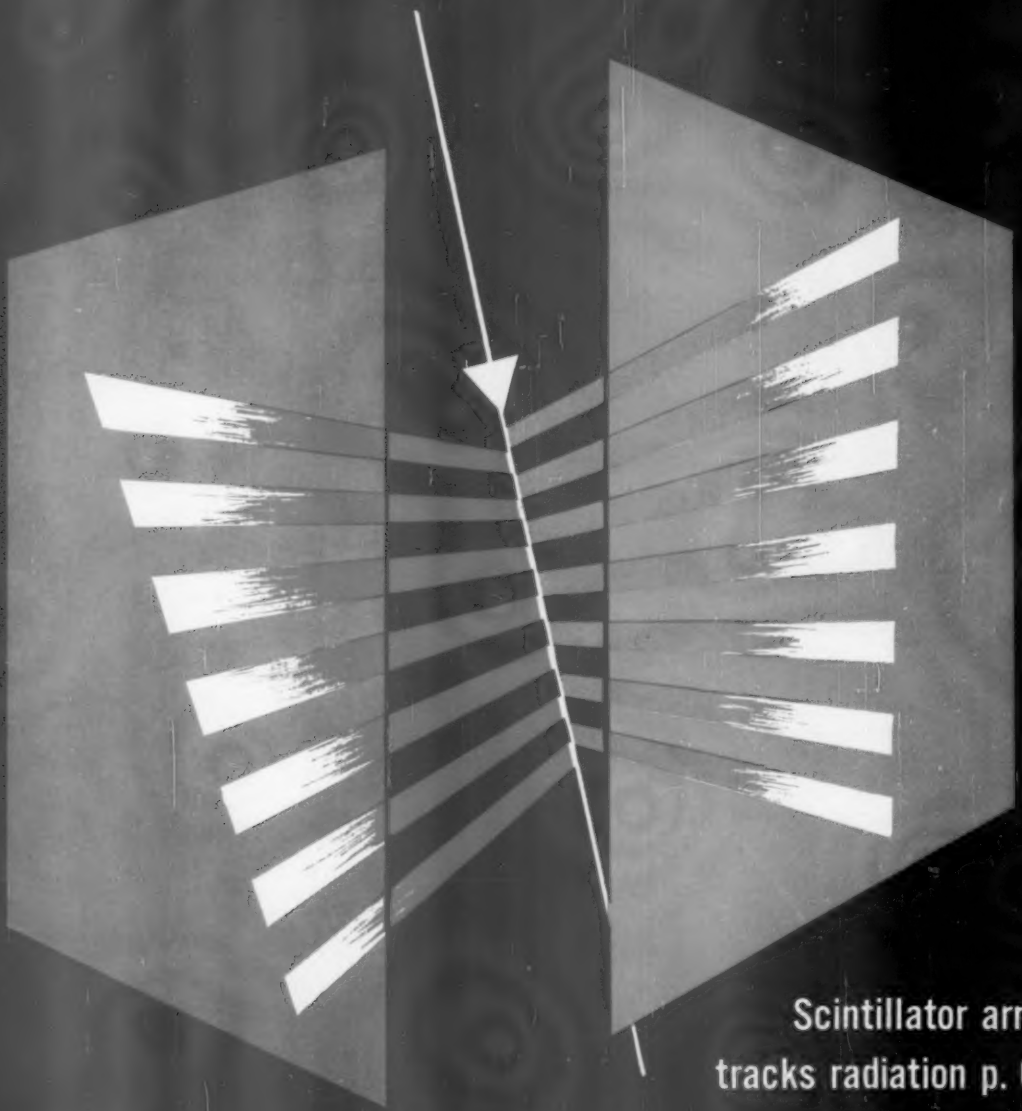
NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION



Scintillator array tracks radiation p. 60

SCINTILLATION COUNTING–1958

see page 54

New Design . . . Improved Performance . . .

gamma-ray RECORDING SPECTROMETER by nuclear-chicago

MODEL 1820
complete as pictured $2395.00

Model 1820 and more than 30 other new instruments for radiation detection and measurement are fully described in our new Catalog Q, available on request.

Model 1820 Recording Spectrometer combines a precision non-overloading single channel pulse height analyzer, analytical count rate meter, automatic scanning controls, and a recorder in a single chassis for quantitative energy separation of gamma-ray spectra. It offers these outstanding features:

- *completely automatic* scanning and recording of gamma-ray spectra
- exceptional non-overloading characteristics of linear amplifier
- wide choice of full scale ranges, time constants, scanning speeds, chart lengths
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- motor-driven base level potentiometer with automatic shut-off
- window width continuously variable from zero to 10 percent of spectrum range

Model 1820 provides simple controls for greater ease in operation, while offering extremely stable circuitry for high linearity and freedom from drift. It greatly facilitates multiple-isotope tracer analysis, isotope identification, relative isotopic abundance studies, determination of radiochemical purity, and other techniques in which a true record of count rate vs. gamma-ray energy is required.

nuclear-chicago
CORPORATION
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Typical scans made with Model 1820 Recording Spectrometer using DS5-3P scintillation detector with 2" x 2" solid crystal. Window width was ¾ volt during all four scans. Energy figures are in mev.

NUCLEONICS

ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION

VOLUME 16 NUMBER 6

JUNE 1958

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About NUCLEONICS

LUNCHEON SPEAKER, AEC Commissioner John Floberg, right, talks with Howard Mateer, publisher of NUCLEONICS (left) and Eugene Zuckert, former Commissioner

Communication—Our Business

Fundamentally communication is our business. Normally our medium is the printed page, but this is often supplemented by reader services of various types and has now expanded to a small beachhead involving meetings. What we are backing into telling you about is that NUCLEONICS sponsored a seminar on "What the Foreign Atomic Energy Market Means to U. S. Industry in 1958" in New York City last month. Designed to highlight this market in the year of the second Geneva Conference and increased cooperation between the U. S. and Euratom (see Editorial, p. 53), the seminar brought ten speakers on various aspects of the subject to a platform in the Savoy-Plaza Hotel before an audience of 150. Speakers at the morning panel session, and participants in the luncheon are shown elsewhere on this page. The afternoon was devoted to three talks—on the 1958 Geneva Conference by Oliver Townsend of the Atomic Industrial Forum, on the foreign market for atomic energy equipment by Frederick Warren of Pickard-Warren-Lowe Associates and on how American nuclear companies are selling abroad by John Kenton of NUCLEONICS.

Frankly, after going through the headaches of running the meeting we'd just as soon stick to our last, but our audience seemed so appreciative and we ourselves learned so much that we might try again some time. In any event we did succeed in getting out the magazine betimes and urge you to inspect the wares displayed within.

—The Editors

PANEL AT MORNING SESSION defined status of U. S. program and needs abroad; left to right J. D. Luntz, R. H. Ellis, H. L. Davis, all of NUCLEONICS, Corbin Allardice of the World Bank, and James Girdwood, Advertising Sales Manager of NUCLEONICS

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Coming Features in NUCLEONICS

Next Month

Nuclear Rockets
Ultrasonic Decontamination
Neutron Spectrum Measurements

Later Months

Nuclear Fuels
Reactors on the Line, No. 6—Oak Ridge Research Reactor
Shock Waves in Reactor Containment
Environmental Surveys

A major advance in South American science is this recently activated research reactor at São Paulo University. Shown here is the working floor level of the 5-Mw unit.

Model of B&W Swimming Pool Reactor. Operative units are now supplying nuclear data at leading universities and research centers.

First South American reactor is operating at Brazil's University of São Paulo

Designed to produce 5000 kw of power . . . the highest capacity of any "swimming pool" type of reactor in existence . . . this new research reactor will play an important role in Brazil's contribution to the fields of medical, biological and industrial nuclear research. Operating successfully at the University of São Paulo, it has achieved Latin America's first sustained nuclear fission. The "swimming pool" reactor's name is derived from the water-filled concrete pool in which the core is submerged.

The reactor and the fuel elements which make up the reactor core were designed, fabricated and installed by The Babcock & Wilcox Company. The fissionable material in each fuel element is 20 percent enriched uranium 235.

Typical of B&W thoroughness and sound engineering were the extensive tests and research that assured successful operation. These included criticality experiments conducted in a similar research reactor in the U. S. under conditions duplicating those expected in Brazil. The result is an important step in President Eisenhower's "Atoms For Peace" program, which was designed to encourage and aid the development of nuclear energy for peacetime uses throughout the world.

In nuclear power development, B&W is a leading source for power reactors, propulsion reactors, research reactors, fuel elements, reactor components and experimental reactor development. The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

AE-50

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ATOMIC ENERGY DIVISION

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soft beta counting
-simple
operation

THE TMC LP-2A LIQUID PHOSPHOR COUNTER

For precise counting of soft beta emitters such as Carbon 14, Tritium, Sulphur 35, the TMC Model LP-2A Liquid Phosphor Counter offers many exclusive advantages in both operation and design, proven in the various applications of nuclear radiation in all fields of research. Here are the primary reasons for the LP-2A's outstanding performance—

DETECTION . . . Two refrigerated photomultiplier tubes—specially selected and matched for highest sensitivity and lowest accidental coincidence noise—measure and analyze light output. The sample holder is equipped with an interlocking shutter mechanism which permits sample changing without removing phototube high voltage. Overall electronic gain is 100,000 with 0.15 us. rise time.

COUNTING . . . A fast coincidence pulse height analyzer uses coincidence on all levels and pulse height analysis on both amplifier channels. This means that pulses, to be counted, must be analyzed by both detectors simultaneously. (If one pulse falls in the upper channel and the other in the lower channel, it is counted as a lower channel event.) This considerably reduces coincidence noise and photomultiplier selection. Operation with separated channels is also possible.

READOUT . . . Two precision scalers are used—each with a 2.5 us. resolving time and total capacity of up to 10^7 counts, on three decade scaling strips and a mechanical register. One scaler counts all pulses between lower and middle level settings. The second scaler counts pulses between the middle level and upper level (to infinity if desired). This feature permits simultaneous counting of two isotopes with an energy difference as small as 3 to 1.

DYNAMIC DISCRIMINATOR RANGE . . . The dynamic discriminators will maintain stable operation on as little as 5 volts, thus giving them the extremely wide range of 20 to 1. This is of primary importance when counting different isotopes simultaneously. The Model HV-4A Ultra-Stable High Voltage Power Supply may be precisely set to a given voltage and this setting may be later duplicated within a fraction of a volt. Stability is 50 parts per million/hr. or 200 parts/million/day, resulting in minimum drift. This means simpler operation because minimum adjustment is required.

UNITIZED CONSTRUCTION . . . Each component (dual amplifier, analyzer, dual scaler, high voltage source) has its own power supply, thus permitting easy servicing and testing of individual units. All units are housed in a rugged enclosed cabinet and cooled by forced filtered air.

The accurate, dependable components and advanced circuitry design make the LP-2A a research instrument capable of optimum performance and versatility.

Detailed data concerning the LP-2A or catalog "C" which describes the complete TMC line are available on request. TMC also invites your inquiries concerning specific instrumentation recommendations.

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ZIRCONIUM

Now zirconium takes another giant step ... from an expensive rarity to a readily available special-purpose metal. Capacity is now on hand for not only A.E.C. requirements but also commercial markets. And, as in titanium, Mallory-Sharon is in the forefront of this rapid development.

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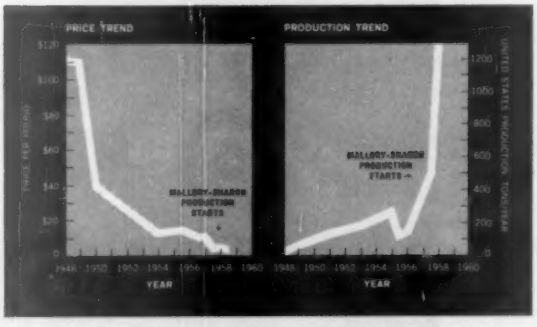
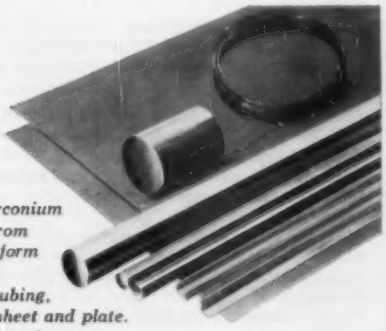


For lower prices — *Greater availability will definitely be reflected in lower prices. In many cases, the improved performance of zirconium parts much more than offsets their higher material cost.*



For mill products — *Zirconium is now available from Mallory-Sharon in the form of rounds, bars and billets, wire, tubing, strip, foil, sheet and plate. Quality and properties are carefully controlled at every stage of production.*

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Integrated producer of Titanium • Zirconium • Special Metals

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LONG RANGE CAREERS

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ANALYTICAL

Degree essential. Experience as required.
Preliminary analysis: Conduct preliminary analysis and design of overall power reactor systems and components.
Shielding analysis: Advanced studies and analysis on stationary and mobile plants.
Systems analysis: Engineering direction on reactor plant design.
Control analysis: Reactor kinetic and overall nuclear power plant control. Hazard analysis. Analog and digital computers.
Core analysis: Includes criticality, temperature, void and power coefficients, control effectiveness and fuel cycles.
Stress analysis: Structural, thermal, and dynamic stress analysis of high temperature reactor systems.
Heat transfer analysis: Reactor systems – dynamics and thermo-dynamics of fluid flow.
Operations: Foreign and domestic – for checkout, start-up and training.

DEVELOPMENTAL

Requires related experience and applicable degree.
Fuel elements: Metallurgists for R&D on nuclear fuel materials, including radiation effects, evaluation of uranium and thorium alloy, and ceramics. Also for mechanical fabrication development for these materials.
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Theoretical, Experimental, Solid State Physics, Health Physics, Materials Research, Mechanical Component Development.

Write for more details of exciting career opportunities at AI.
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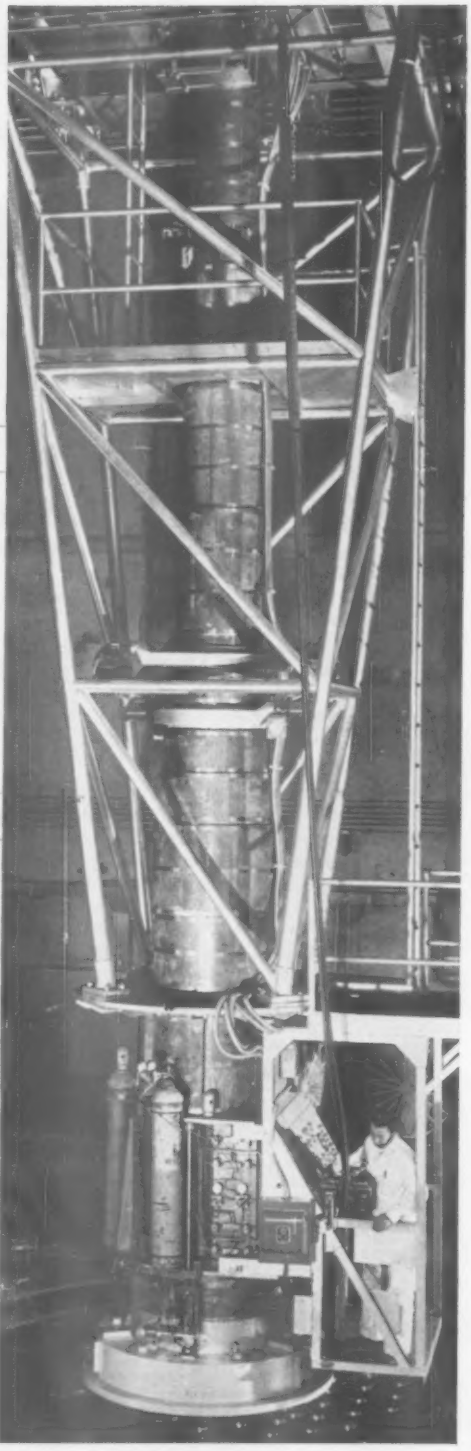
PIONEERS IN THE CREATIVE USE OF THE ATOM



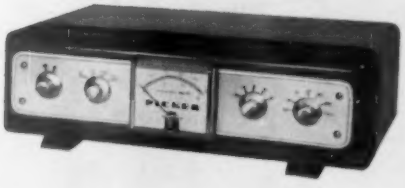
SRE Fuel Handling Cask. The Sodium Reactor Experiment and the Organic Moderated Reactor Experiment are both in successful operation. Plans for several central station plants based on these experimental power reactors are underway. AI is also conducting an advanced power reactor study for Southwest Atomic Energy Associates. Overseas, AI has already sold 5 reactors, and is affiliated with ASEA of Sweden and the new company INTERATOM (with DEMAG, West Germany).

fine nuclear instrumentation for counting rate measurement

An integrated Picker-quality combination for precision measurement of counting rates and determination of changes in counting rate with time.

PICKER nuclear instruments

2805 PRECISION RATEMETER



Unequalled stability: *only ratemeter available so stable that it needs no zero adjustment control*

Range of 5 time constants (0.5 to 50 seconds) for fast reading response or for minimal statistical fluctuations

Range of 7 counting rates (300 to 300,000 CPM) for accurate measurements from low background up to high activity levels

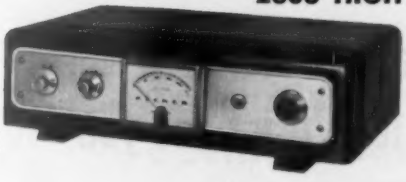
Precision discrimination from 25 millivolts to 2.5 volts

Stable linear amplifier

Proportional-pitch audio signal

1% circuit accuracy

2803 HIGH VOLTAGE SUPPLY



Returns to within 0.5 volts out of 1,000 volts when turned off and restarted later

High voltage normally changes less than 0.001% per volt change in line voltage

Daily drift is less than 0.02% with constant line voltage

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2990 RECORDER

10 chart speeds from 12"/min to ¾"/hr selected by direct gearshift

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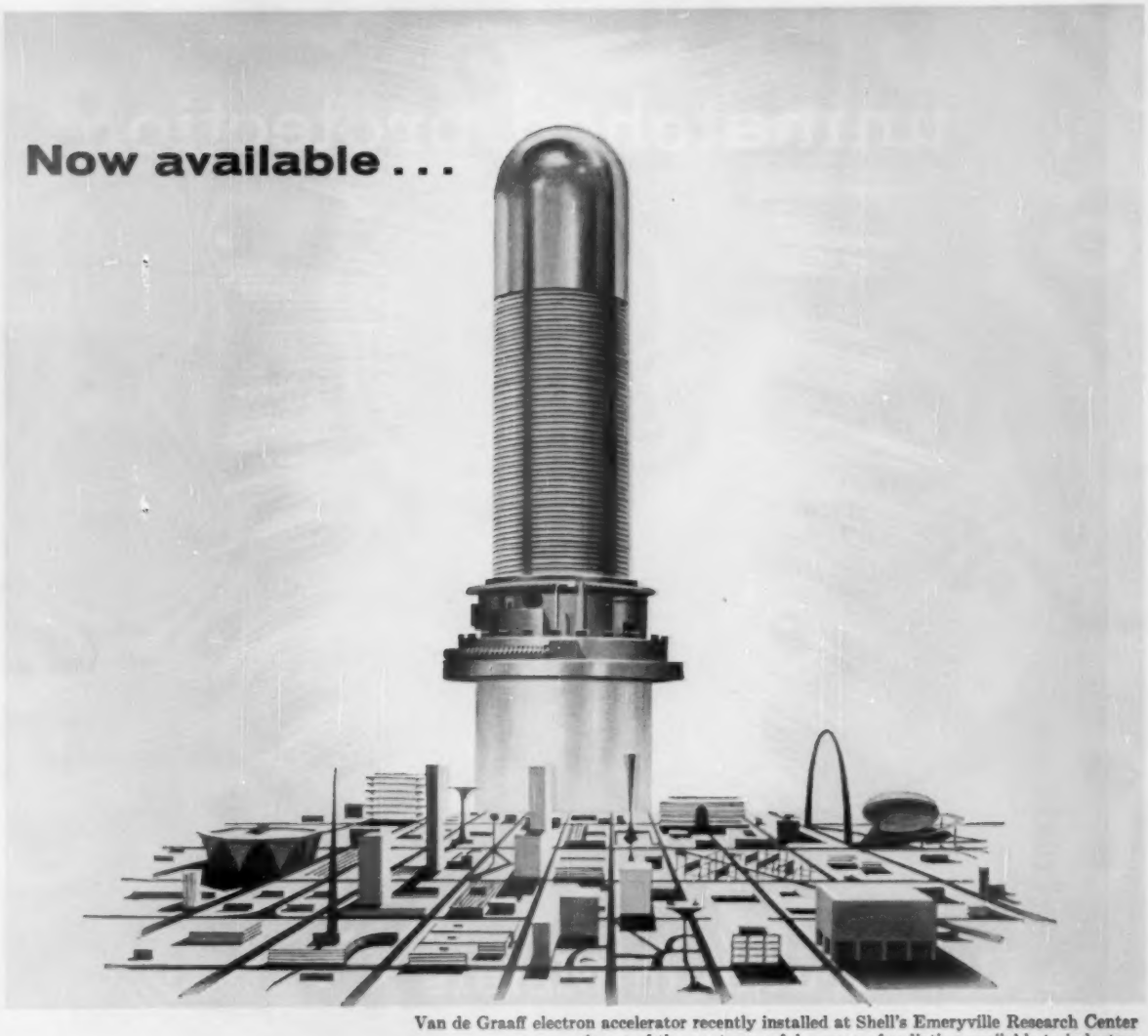

Van de Graaff electron accelerator recently installed at Shell's Emeryville Research Center is one of the most powerful sources of radiation available to industry.

a radiation-resistant grease for commercial nuclear applications SHELL APL GREASE

Nuclear applications bring new complexities to the field of industrial lubrication. Not only is the lubricant required to withstand unusual service with respect to temperature, speed, load and oxidation, but it is also exposed to the damaging effects of neutron and/or gamma or beta radiation.

To meet this challenge, Shell Research has developed a practical radiation-resistant grease for use in nuclear reactors and their component parts . . . Shell APL Grease.

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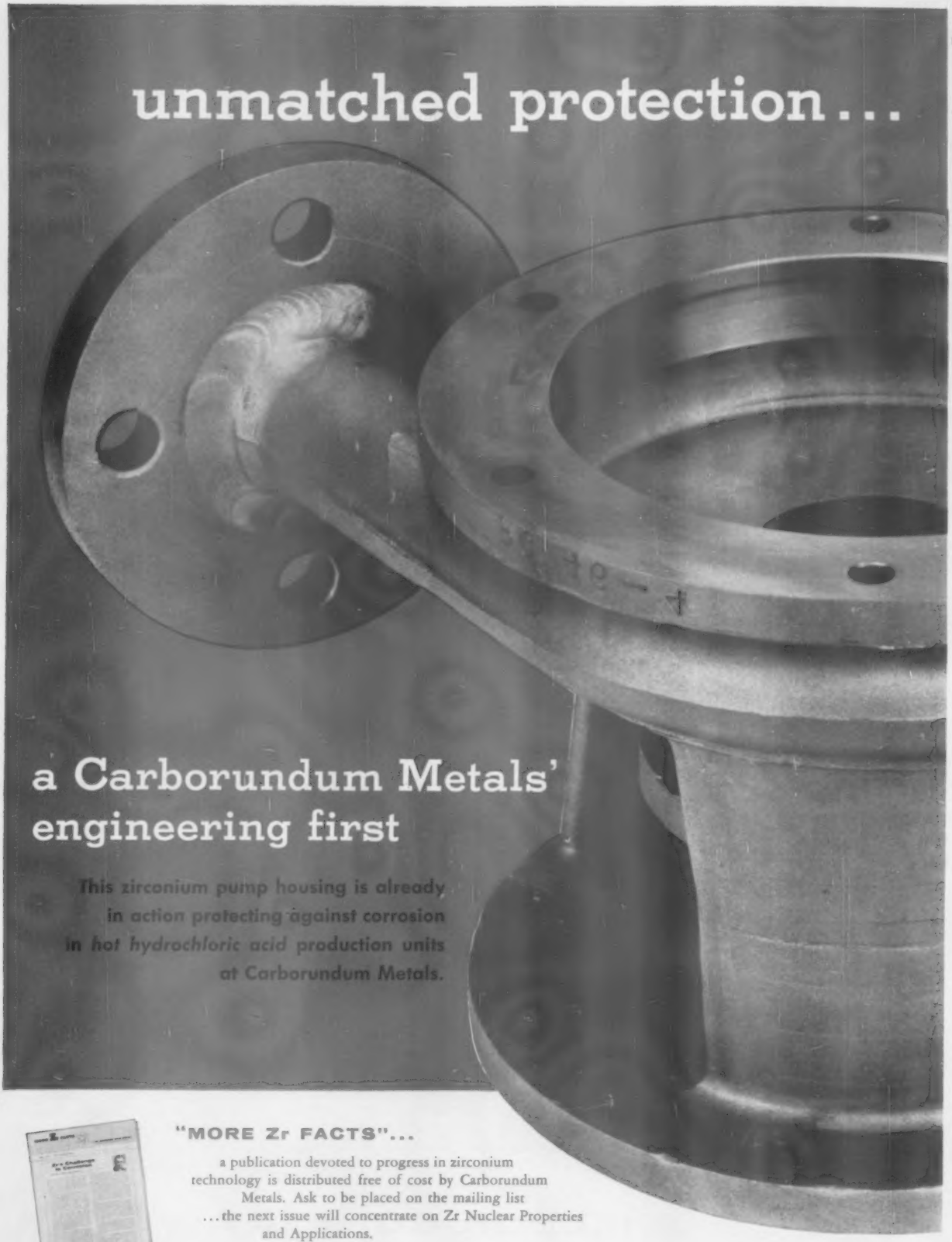
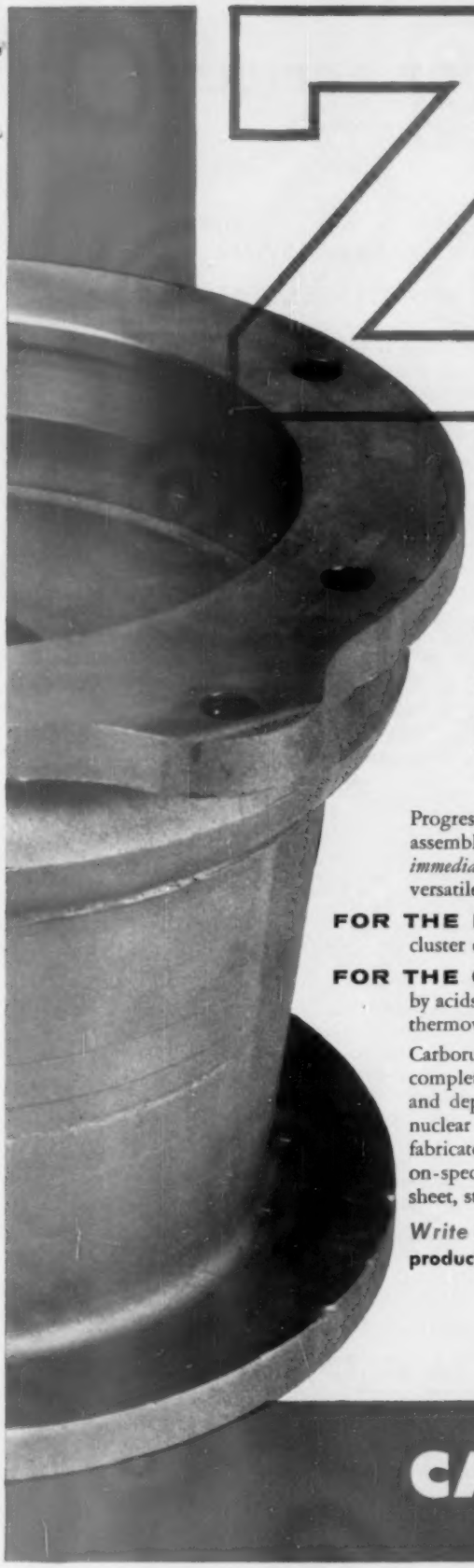


a Carborundum Metals' engineering first

This zirconium pump housing is already in action protecting against corrosion in *hot hydrochloric acid* production units at Carborundum Metals.

"MORE Zr FACTS"...

a publication devoted to progress in zirconium technology is distributed free of cost by Carborundum Metals. Ask to be placed on the mailing list ...the next issue will concentrate on Zr Nuclear Properties and Applications.



Zr pump casting

cast...welded and machined for long-term action!

Progress in zirconium fabrication techniques is evidenced in intricate cast-weld assemblies such as this impeller housing. Similar zirconium components are *immediately available* through Carborundum Metals for system designs where the versatile properties of this metal provide outstanding benefits:

FOR THE NUCLEAR INDUSTRY—low neutron cross-section for fuel cluster ends and other reactor components.

FOR THE CHEMICAL INDUSTRY—super corrosion resistance to attack by acids and caustics on basic components such as valves, pumps, heat exchangers, thermowells and reaction tanks.

Carborundum Metals' pioneer experience in zirconium production, its two completely modern and fully integrated producing facilities provide a ready and dependable source for every zirconium requirement... in commercial and nuclear grade sponge and ingot. Close working relations with highly qualified fabricators permit Carborundum Metals to provide definite quotes and assure on-specification delivery of welded or seamless zirconium tubing, zirconium sheet, strip, bar, rod and foil.

Write today **for latest price schedules and data sheets on all zirconium products. Address inquiries to Dept. 91-801.**

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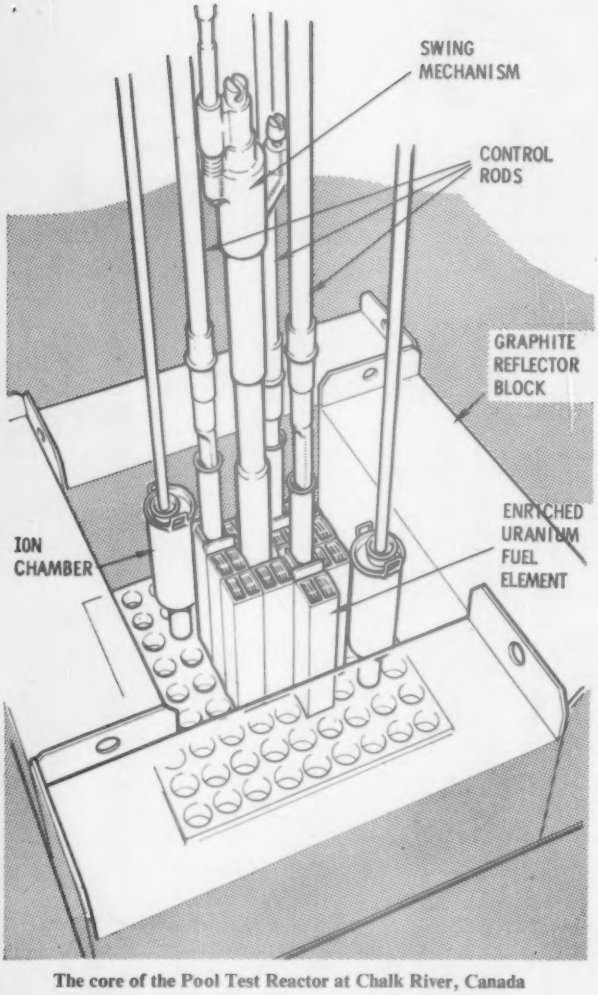
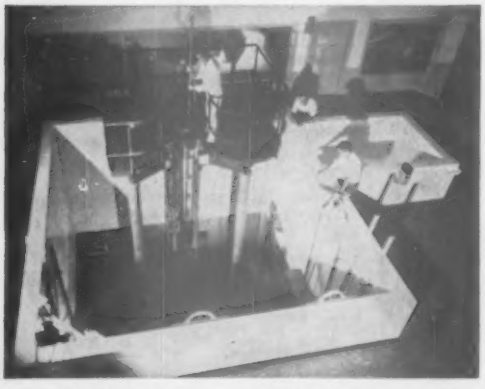
DESIGNED FOR FASTER, MORE ACCURATE "SWING" MEASUREMENTS



The core of the Pool Test Reactor at Chalk River, Canada



Assembly and testing of the Pool Test Reactor at Chalk River, Canada

another CANADAIR nuclear ACHIEVEMENT

In Canada's nuclear energy program the need arose for a method of determining the reactivity contributions of nuclear fuels and the absorbing effects of materials used in the construction of reactors.

Under contract from Atomic Energy of Canada Limited, Canadair's team of nuclear engineers designed, constructed and assembled the appropriate swimming pool type reactor, and a mechanical Swing Mechanism that would perform these reactivity measurements. This Swing Mechanism is an original design developed by Canadair.

The Swing Mechanism consists of an hydraulically-operated vertical assembly in which two samples of reactor materials, one of known, and the other of unknown reactivity, are alternately placed at the position of maximum neutron flux to provide an accurate measure of the reactivity of the unknown sample. High accuracy is achieved through very fast transit times and extremely close control of sample trajectory and cycling periodicity. Considerable flexibility is in turn possible through varying the length of stroke and ratios of successive half-cycle times and transit times.

The Canadair Swing Mechanism, of aluminum and stainless steel construction throughout, is applicable to any small core reactor but is particularly suitable for a pool type inasmuch as the water in the pool serves triply as a reservoir for the hydraulic system and as a coolant and moderator for the reactor. The sample carrier within the Mechanism can be reloaded under water with simple remote handling tools permitting safe, quick loading of already irradiated samples.

Canadair's nuclear division manufactures reactors, reactor components and specialized physics instruments to the most exacting individual specifications, and its team of experienced nuclear engineers and scientists is always available for expert consultation and advice on nuclear problems related to any field . . . basic research, generation of heat and power, medicine, agriculture and general industry. Inquiries are particularly invited from universities and laboratories.

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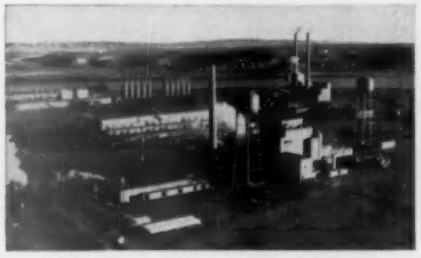

Project: construction of large plutonium production plants. KE work involved reactors, shielding, extensive instrumentation, stainless steel piping, machinery installations and other complex construction. KE completed job ahead of schedule and below the budget.

Cost-saving and time-saving ingenuity, plus a wealth of nuclear experience—these are two of many reasons why Kaiser Engineers has been selected for so many of America's challenging nuclear projects. To date, value of KE nuclear projects amounts to more than $165,000,000.

KE provides complete nuclear engineering and construction services—including concept feasibility, reactor criteria, facility design, construction and test operations.

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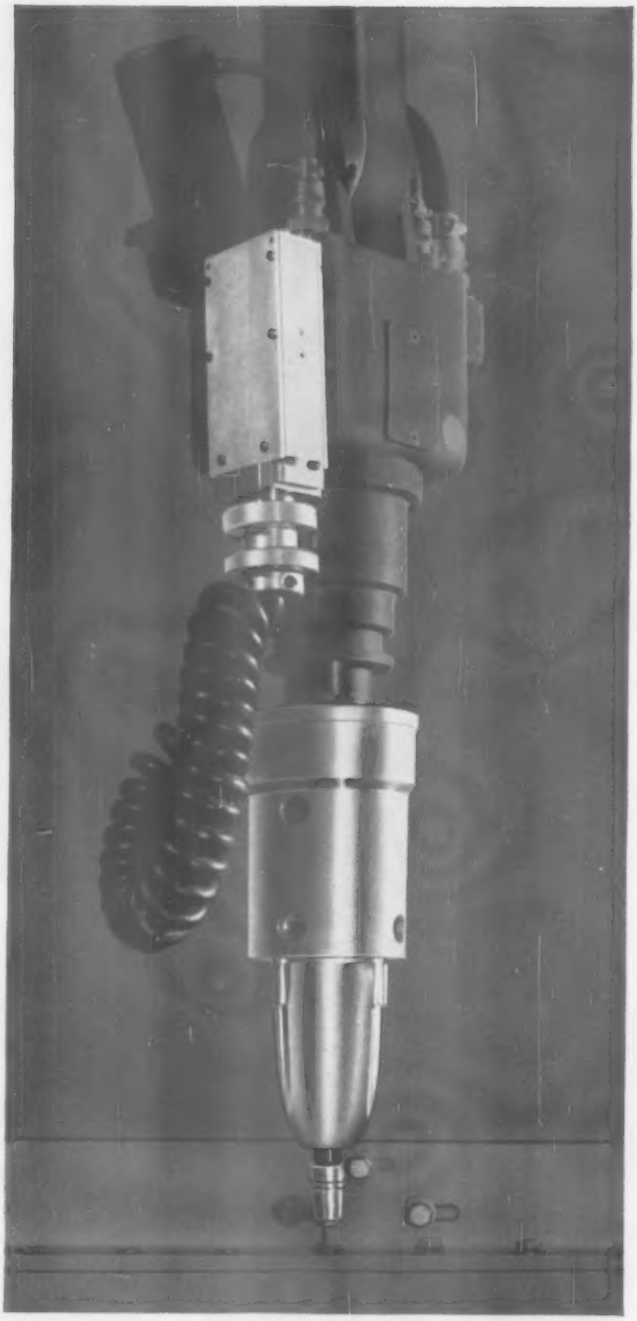
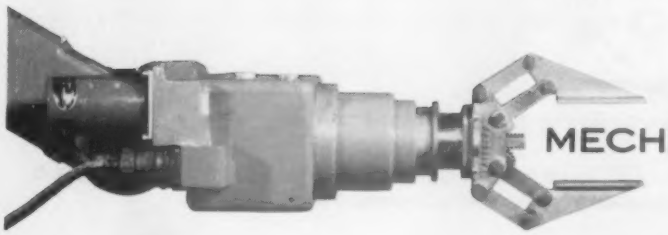


POWER TOOLS EASILY ATTACHED TO MECHANICAL ARM: tools snap into place on the forearm. A simple electrical connection at the power take-off, which is permanently mounted on the forearm, completes the placement.



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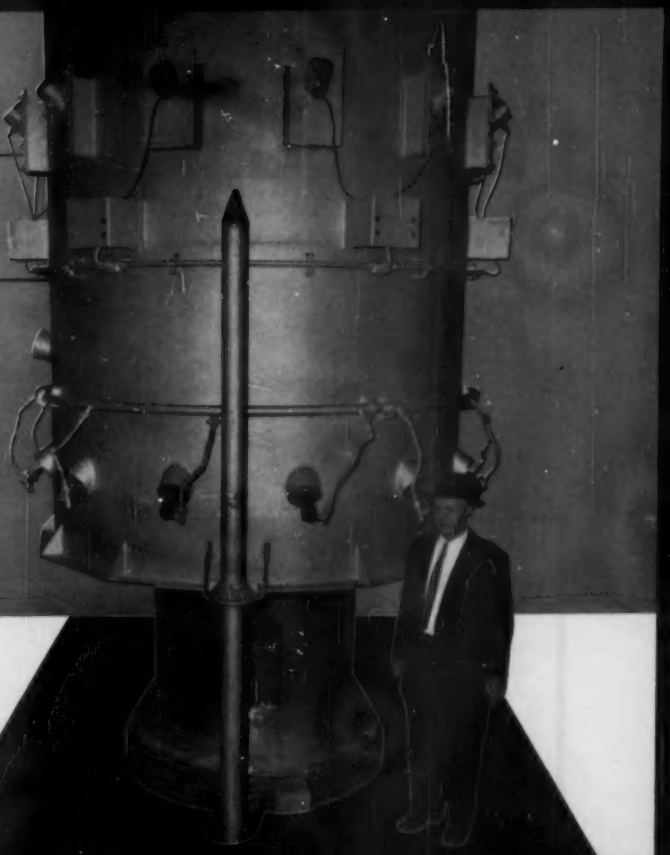

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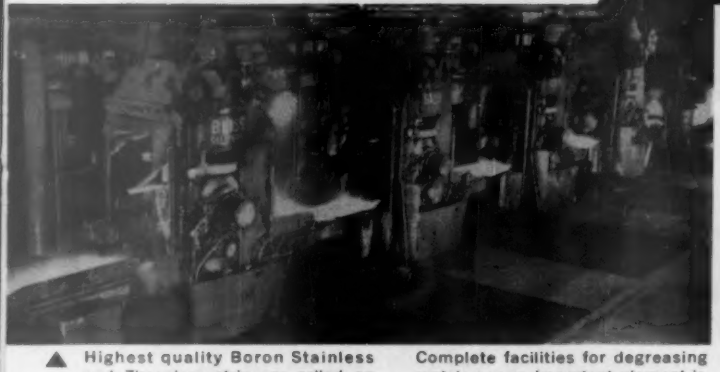

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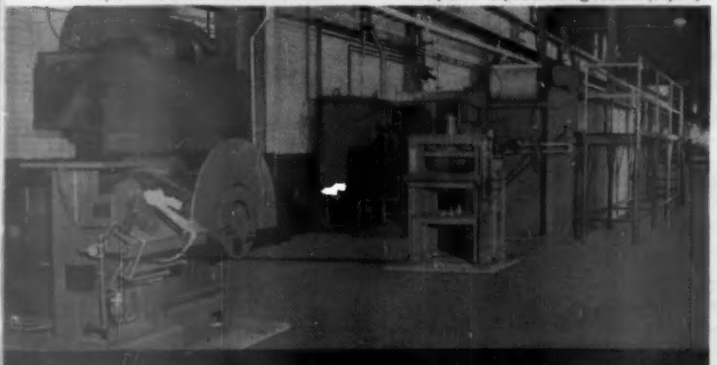

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Progress in POWER GENERATION

Innovation and refinement in nuclear power reactors will be the most significant development in electric power generation during the next ten years.

In that time, utilities engineers through much of this country will routinely weigh the advantages of nuclear versus conventional generating stations. And increasingly, the nuclear station will be specified.

	DESIGNATION	PURPOSE	STATUS	FUEL	COOLANT	MODERATOR	REFLECTOR	POWER	SPECIAL FEATURES
swr	Steam Water Reactor	Power generation.	Under study by NDA and East Central Nuclear Group	UO_2 (natural uranium)	Steam (H_2O)	D_2O	D_2O, graphite	200,000 KWe	Direct cycle. Produces superheated steam approximately 1050°F., 2000 psi. High cycle efficiency, low fuel cost.
sdr	Sodium Deuterium Reactor	Power reactor prototype to demonstrate feasibility of system.	Part of AEC Power Reactor Demonstration Program. Conducting mechanical and chemical tests on design features. Preparing preliminary design.	Slightly enriched uranium	Sodium	D_2O	D_2O	10,000 KWe	Combines best moderator with best coolant in single system yielding high efficiency steam cycle conditions. Potential utilization of natural uranium fuel in higher powered version.

Two NDA reactors for progress in power generation.

Through its work for Government and industry during the past ten years, NDA has developed a highly qualified reactor team. NDA reactors aim at the delivery of steam at temperatures and pressures suited to modern turbines. Emphasis is placed on advanced technology using high temperature-low pressure coolants, high neutron efficiency moderators and the use of natural or low enrichment uranium fuel.

NDA's team consists of almost 400 reactor scientists, engineers and supporting personnel with a single business—design and development of high performance nuclear reactors. Inquiries are invited from electric companies or study teams.

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ROUNDUP of Key Developments in Atomic Energy

Euratom Agreement is U. S. Industry's Hope for Sales

With four to six large power reactor construction awards expected to be up for grabs in Euratom countries this year, American manufacturers have their eyes on Washington—watching to see if the government can meet the challenge of implementing and ratifying the recently-concluded U. S.-Euratom agreement before Congress adjourns this summer.

The six Euratom countries early this month accepted the U. S. offer of financial help for purchase of up to 1-million-kw of water-cooled reactors. Under the agreement the U. S. will grant a $135-million credit for 12–20 at 3½% interest for this purpose; the maximum of 1-million-kw will be divided equally —250-Mw each—among France, Germany, Italy and the Benelux countries. Further, the U. S. will contribute $10-million/yr for five years for research-development provided Euratom puts up a like amount. Besides this "memorandum of understanding," which embodies all the principles of the arrangement, there are now also being completed a "memorandum of agreement" under Sec. 123 of the 1954 Act, which spells out the details and which must lie 30 days before JCAE; and a brief treaty under Sec. 124 formalizing the deal, which must be passed by both Houses of Congress. U. S. industry is hoping the memorandum of agreement at least can fulfill the 30-day validating period this summer.

Without such ratification, it is generally conceded, the U. S. reactor business will continue to go begging in Europe—or reactor orders may well go to British manufacturing groups, almost by default.

Only two days after Euratom endorsed the U. S. pact, the Community established formal relations with Britain; serious talks on a U. K. reactor sales agreement will begin after review of the U. S. agreement by Congress. Britain is seen by U. S. and European observers as being already ahead of the U. S. in bargaining position by virtue of giving guarantees on fuel element performance, and reportedly also offering special deals on fuel supply as well as financial assistance on capital costs. The British government, as has frequently been pointed out, not only is aggressive in supporting that nation's nuclear industry in its export sales drive, but also is in a particularly good position to render aid on fuel. This is because, unlike the situation in the U. S., the only fabricator of fuel elements in Britain is the Atomic Energy Authority itself: no private firm has been permitted to enter the business of fashioning fissionable material into plates, slugs or rods as a commercial service.

With this formidable competition facing them, American reactor builders were seeking to analyze what the U. S.-Euratom agreement (NU, April '58, 19; May, 20) means to them. The agreement has been widely misunderstood. *Not* a pact providing for sale of 1-million kw of U. S. water reactors to Euratom countries, it is simply an agreement laying down the terms under which U. S. manufacturers can offer, and Euratom utilities receive, a better deal on purchase of reactors up to a maximum of 1-million kw. Designed to make it easier for U. S. industry to compete, it is an arrangement under which a million kilowatts of reactor capacity may be bought—or none: it is up to Euratom utilities to buy and up to U. S. industry to sell.

Seeking Cost Control

The agreement seeks to achieve this goal by limiting the risks that European utilities must assume in buying a reactor, by bringing under control the "profound uncertainties" in the fuel cycle. This it approaches by two routes. First, by striving to

Italy signs with U. K.; Euratom blows whistle on British

Italy's government-owned nuclear enterprise AGIP Nucleare, which is buying the first Calder-type reactor Britain sold abroad (NU, Dec. '57, 17), last month made more grandiose news. As negotiations leading to contract-signing with Britain's Nuclear Power Plant Co. of Knutsford, Cheshire, neared conclusion, AGIP Nucleare announced that it and NPPC had signed a separate, seven-year collaboration pact calling for a "vast" information-exchange program on power reactor research, construction, operation and personnel training. Simultaneously AGIP Nucleare announced its intention to build nine more nuclear power plants in the next nine years, to follow the one now scheduled to start up in 1962 at Latina, 40 mi south of Rome near the World War II Anzio beachhead.

Meanwhile NUCLEONICS learned in Brussels that the Euratom Commission is questioning the legality of the AGIP-NPPC contract for the first reactor, and is putting a stop to negotiation of similar agreements by Britain with Germany and Holland. The objection is based on clauses of the agreement providing a direct supply of fuel from the U. K. to AGIP and subject to British inspection and control, whereas the Euratom treaty provides that all fuel entering the Euratom area must come under the official Euratom umbrella. However it is believed the AGIP-NPPC contract will be permitted to operate since it is covered by the quite broad Anglo-Italian bilateral agreement signed last December, before the Euratom agreement became operative. Euratom officials say the six-nation pool will gladly conclude a master agreement with Britain covering similar bilateral reactor purchases in future and containing suitable clauses conforming to requirements of the Euratom treaty.

establish a maximum that fuel fabrication can cost, possibly through three-way agreements on core supply between the purchasing European utility, the supplying U. S. fuel fabricator, and AEC—with AEC guaranteeing the difference if the established maximum cost is exceeded. Thus the purchasing utility could be sure of its maximum obligation, would not be faced with an open-ended commitment. Second is a similar provision in terms of core exposure time in the reactor, again with AEC as the party of the third part standing ready to fill the gap between actual and predicted core-life, either with money or with replacement of the reactor's fuel.

It is understood that a complicated but mutually agreeable formula has been worked out, as part of the U. S.-Euratom agreement, that translates this vague-sounding principle into workable procedures.

In effect such arrangements would permit U. S. industry to overcome the greatest handicap it has been hobbled by in the foreign market to date: its inability to match British guarantees on burnup and costs.

[Early this month NUCLEONICS learned that at least three major U. S. reactor builders had given fuel warranties in their bids on the SENN project.]

Moreover, fuel supplied by the U. S. under the agreement would be sold to Euratom and financed over a period of 20 years, more or less the amortized life of the reactor. This eases the capital-cost problem for the dollar-short European utilities, while at the same time meeting the requirements of the Euratom treaty, under which the Community must own all fissionable material, as AEC does in the U. S.

Involved here is $100-million worth—33 tons—of U^{235}, exclusive of fabricating costs, for 1-million kw.

Four are already on the docket for contract award this year: two in Italy, one each in Belgium and West Germany. Bids on Italy's SENN project have already been received from five U. S., four British and one French firm or group of firms; they are now being analyzed (*see p. 19*). SIMEA in Italy (NU, March '58, 19); Germany's big Rheinisch-Westfälische Elektrizitätswerke (NU, Nov. '57, 19); and Belgium's SEEN syndicate are also due in 1958.

U. S. reactor builders, anxiously eyeing this long-sought business, look to ratification of the Euratom agreement this year to put them on an even footing with British competitors in going after the business. They are frank to concede privately that under existing conditions it is impossible for them to compete. If the agreement is not validated before Congress goes home, says one experienced reactor sales executive, "we're counted out as far as these four reactors are concerned. If we wait till next April, these orders will go to England."

"The real problem," he adds, "is lowering fuel costs. We just can't compete with Britain unless we can do that. The difference in capital costs is negligible."

AEC Authorization Requests Pruned by Budget Bureau; JCAE Democrats May Impose Pu, D_2O Reactors

The question dominating the nuclear power controversy in Washington last month, following submission of AEC's fiscal 1959 reactor construction program, was this: To what extent will AEC's Democratic antagonists in Congress attempt to expand the program?

AEC punctuated the collapse of four months of negotiations on a long-range reactor development program by submitting to the Joint Committee on Atomic Energy a fiscal-'59 construction program promptly denounced as inadequate by JCAE Democrats. The attack was led by Chairman Carl T. Durham (D—N. C.) and Vice-chairman Clinton P. Anderson (D—N. M.).

The Democrats, particularly incensed over the exclusion of a plutonium production facility and a 100 Mw(e) heavy water reactor, prepared to force these reactors and possibly others back into the '59 program. They also prepared to go ahead with appointment of a reactor panel to lay the groundwork for consideration of a long-range program next year (NU, May '58, 17).

In presenting its '59 authorization bill to JCAE, AEC asked for authority to commit $115,224,000 for federal and private reactor development in the year beginning July 1. The request covers $88-million for its own development program (including $51-million for the JCAE-sponsored gas reactor, which AEC wants industry to have first crack at), and $27-million to support the cooperative reactor demonstration program.

Projects Killed

Cut out of the bill before it cleared the Budget Bureau were seven projects estimated to cost $149.5-million. These included the heavy water reactor ($65-million), a materials and an engineering test reactor ($35-million), $30-million worth of small reactors for the military, a tanker propulsion reactor ($7-million), $5-million earmarked for the Argonne boiling reactor (ARBOR), and $8.4-million for metals-ceramics research facilities.

AEC's since-resigned General Manager Kenneth E. Fields, explaining to JCAE why the $35-million for new test reactors was not in the authorization bill, said AEC had decided to attempt encouragement of private facilities by entering into longterm contracts for space in new reactors. He said the Commission would ask JCAE to help clarify AEC's authority to negotiate such contracts.

In addition to the $115-million sought for reactor development, AEC requested $105-million for construction of weapons, research-training and general facilities, $2.2-million for Project Sherwood (controlled fusion), and $9.4-million to complete two particle accelerators under construction at Princeton and Cambridge. Total new authority sought for existing and new projects was $231.7-million.

Another $17.3-million, authorized by Congress in prior years, was dropped from the AEC construction program. AEC said it has decided not to go ahead with these four projects: a fabrication plant for special nuclear materials ($5-million); a metal treatment plant at Fernald, Ohio ($850,000); $8.5-million for ARBOR; and the $3-million food irradiation reactor planned for the Army.

Projects Provided For

Aside from the $51-million gas reactor, these projects were listed under the $88-million reactor development request:

- Heavy water component test reactor, $8-million. AEC said it was not ready to go ahead with a 100 Mw(e) reactor in fiscal '59, would build an experimental unit instead, at Savannah River.
- Modification of reactor experiments, $6.3-million. To be modified in line with "logical growth" of technology are OMRE (Organic Moderated Reactor Experiment),

EBWR (Experimental Boiling Water Reactor), and Borax (Boiling Reactor Experiment).

- Prototype package power plant, $3-million. A 10 Mw(th) reactor designed for quick erection at military bases—to be purchased on bid.
- Fast reactor testing station, $1,367,000. A "minimum" facility, capable of expansion, to support a safety testing program on this concept at AEC's Nevada test site.
- Army reactor experimental area, $1-million. Concentration of support facilities for the Army reactor program at the National Reactor Testing Station, Idaho.
- Integrated fuel reprocessing plant, $3.5-million. One of four projects planned for fuel cycle work, the facility will be built at Oak Ridge on a pilot plant scale.
- Modification of existing processing facilities, $15-million. To complement the Oak Ridge project, plants at Savannah River, Hanford and Idaho will be modified to provide for large-scale reprocessing of nonproduction spent fuels.
- Additional hot cells, $5-million. An unspecified number of hot cells to be built at various AEC laboratories for fuel cycle work.
- Fuels Technology Center, $5-million. To provide a new wing to the Center now under construction at Argonne (*see p. 21*).

The bulk of the $27-million in new authority requested for the cooperative demonstration program has not been specifically earmarked by the Commission, Fields testified. Some $20-million, he said, was sought by AEC to aid second generation projects that may be proposed by industry during the fiscal year. W. Kenneth Davis, AEC reactor development chief, said no specific proposals were involved in the request.

The remaining $7-million for cooperative projects includes $4-million in readjustment of earlier estimates of AEC aid, as well as new money for projects such as PAR (the Pennsylvania Power & Light homogeneous reactor) and the steam-cooled reactor plant proposed by East Central Nuclear Group/Florida West Coast Group. Another $3-million, AEC said, was required for "preconstruction research and development on fast breeder reactors," presumably in support of the Fermi reactor at Lagoona Beach, Mich.

JCAE was also asked to authorize AEC's proposed contracts with PP&L and the East Central/Florida sponsors.

Britain Drops Plans To Borrow Abroad

The United Kingdom, its ambitious, 19-station nuclear power program showing the first signs of financial fatigue, backed away last month from its plan to seek $1-billion in loan money from the World Bank and private U. S. sources.

Political opposition in some British government quarters, including the Atomic Energy Authority, forced cancellation of the plan—at least for the foreseeable future. AEA felt that reliance on foreign financial support for the nuclear power program would be a severe blow to British pride in the program, that the political disadvantages would outweigh the financial gains.

Informal talks between British and World Bank officials had been held intermittently since even before the 19-station power program was announced early last year. Although the Bank had never received a formal application, it had indicated there were no major obstacles to a 10-year loan supported equally by the Bank and the U. S. financial market.

Direct evidence that Britain was running into capital shortages came in mid-April when a White Paper on the coal, gas and electricity industries disclosed that the target date for completion of the nuclear program had been postponed from 1965 until 1966. The reason: A decision to fill a higher proportion of the country's need for electricity with coal-fired stations "at lower capital cost" than nuclear stations.

Despite its capital difficulties, AEA made it clear last month that its optimism over the atom's ability to compete with coal has not dimmed. Sir John Cockcroft, Harwell director, said last month that nuclear-power costs would fall below coal-power costs in 1962.

9 SENN Bids Under Study; Decision Due This Summer

Argonne National Laboratory teams are already studying enriched-uranium reactor proposals among the nine made to Italy's SENN (Societa Elettronucleare Nazionale) syndicate. The nine bids came from U. S., British and French firms, and were in the 130–150-Mw(e) output range. Natural-uranium systems will be analyzed in England (NU, Sept. '57, 28); SENN is to make a decision later this summer. The bids:

Pressurized water: Kaiser and Westinghouse; H. K. Ferguson and Babcock & Wilcox.

Boiling water: General Electric and Ebasco; Mitchell Engineering Ltd., American Machine & Foundry, and General Nuclear Engineering.

Gas-cooled: General Electric Co. of England–Simon Carves; AEI–John Thompson; English Electric–Babcock & Wilcox Ltd.–Taylor Woodrow; Société Générale Alsthom.

Organic-moderated: Atomics International, Bechtel, and Montecatini.

U. K. disappointment: no thermonuclear neutrons in Zeta

Crestfallen but scrupulously candid, Britain's controlled fusion chiefs told a London press conference that the great majority of neutrons observed in the Zeta machine at Harwell (NU, Feb. '58, 90) have been proved to be non-thermonuclear in origin. This was established by means of a new experimental measuring technique of great sensitivity, in which neutrons were ducted through a collimator into a pressurized cloud-chamber. Energy of the neutrons was measured to an accuracy not previously thought possible, Harwell head B. F. Schonland and fusion project chief Peter Thonemann said. Not only did the energy levels measured indicate that the neutrons were not of thermonuclear origin, but it was also established that the neutron velocities had a preferred direction and were not random as would be expected. "This discovery does not make the Zeta results less significant in any way," Schonland said. "It is an extension of our work which may be of very great value to us. Zeta is being modified to improve its performance and a much more powerful machine is being planned." The Zeta torus is being rewound to improve the coupling of the system and this alone is expected to double the gas temperature from 5- to 10-million degrees.

Merchant Ship Program Under Study by MA-AEC

Eager to maintain what it feels is a lengthy lead over the rest of the world in nuclear naval and merchant ship propulsion, the Administration has set to work to bring into being the world's first privately-owned nuclear merchant fleet.

The immediate aim: to present to Congress this summer or early next year a draft proposal permitting the Maritime Administration to sponsor a Nuclear Ship Cooperative Program—the maritime equivalent of AEC's Reactor Demonstration Program.

Several steamship companies—most operating long-haul tanker and dry bulk cargo vessels—have expressed interest in or have submitted concrete ship construction proposals to MA. However, in general the operators have emphasized that the difference in construction costs between nuclear and conventional vessels is too great for them to bear alone. They have suggested that the government defray some portion of the added cost.

On this basis, MA and AEC are attempting to outline the scope of a cooperative program for early submission to Congress. They are finding the job extremely complicated. There are no easy answers to questions like these: Who should have jurisdiction over a nuclear merchant marine—MA or AEC? Which committees of Congress should consider nuclear ship legislation—the Joint Committee on Atomic Energy or the House and Senate committees handling maritime matters (House Merchant Marine Committee and Senate Commerce Committee)? In short, which part of a nuclear ship is controlling—the reactor or the ship itself?

This last question is especially crucial because each of the major agencies involved has responsibilities under existing legislation: MA under the 1936 Merchant Marine Act, AEC under the 1954 Atomic Energy Act. Can privately-owned nuclear ships be built under the 1954 Act, and if so, where does that leave MA in its jurisdictional responsibilities under the 1936 Act? Should new legislation take the form of an amendment to the 1936 Act, or should special legislation be enacted?

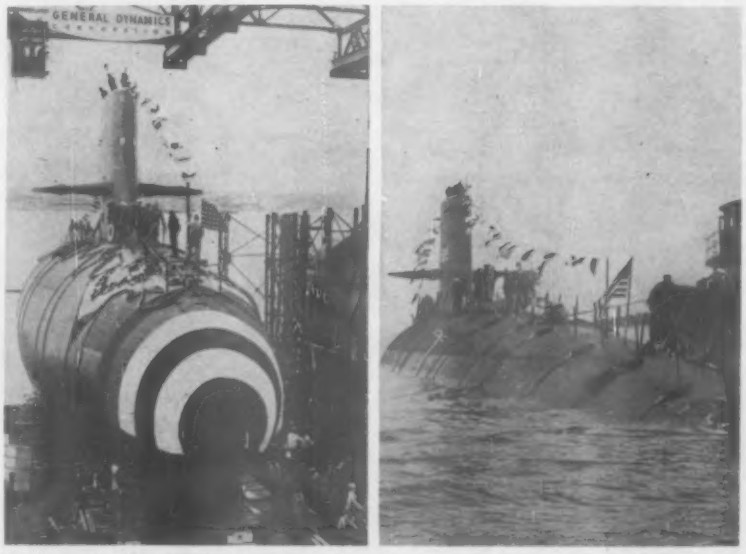
Despite the lack of ready answers, the Administration is keenly anxious to create an atmosphere under which a privately-owned nuclear fleet can emerge and flourish. The hope is that a cooperative or demonstration program can be presented to Congress this year.

In short, the Administration recognizes that nuclear propulsion is being taken seriously by the private operators of tankers, ore carriers and other bulk carriers. In this area of ocean trade, American-flag vessels find the competition from foreign-flag ships particularly stiff; there is no federal subsidy to offset lower foreign costs. During the lag while other maritime nations catch up, at least, U. S. owners could utilize the higher productivity of nuclear vessels to pare the cost differential. And, further, there is strong competition between bulk carriers flying the American flag.

Aside from the competitive aspects of a nuclear fleet, the Administration is also aware of its budget limitations. It is building the first merchant ship and has a second and third under study. But it would like to see government construction give way eventually to private.

Pending a private or cooperative government-industry program, MA and AEC are going ahead with the engineering of a family of ship reactors. A pressurized water plant has already been designed for the NS *Savannah;* a boiling water unit is being engineered for possible installation in a T-5 tanker; and work is going forward on the gas-cooled and organic-moderated reactor concepts. Beyond these, there are the problems of installing the multiple reactors necessary for large passenger and combination (cargo-passenger) vessels, and the feasibility of nuclear-powered, submarine cargo ships.

The immediate task, however, is to get on with the building of a nuclear merchant navy and to enact legislation to make this possible. And running through the debate on such legislation, an Administration official emphasizes, will be this controlling factor: "The number of ships built will depend upon the extent of federal assistance."



Undersea Flyer Takes to Sea

Her horn blaring, Navy's sixth nuclear submarine Skipjack rides down shipways at Groton, Conn., at 4:29 p.m. May 26 and takes to water just as photo (left) was taken. Fourth A-sub built by Electric Boat division, General Dynamics Corp., the sleek new craft when completed in December will open a new era of underwater travel with her great speed and maneuverability (speculations about speed resulting from her tear-drop hull combined with power from her third-generation pressurized water Westinghouse reactor range from 35 to 50 knots and more). Stubby, short and fat (only 252 ft long compared to Nautilus' 320, yet almost as roomy: 2,830 tons as against 3,200), Skipjack has three interior decks instead of conventional two. She lacks usual falsework superstructure atop pressure hull that gives most subs their exterior deck: photos show curvature of her streamlined hull with no flat deck, designed for optimum underwater performance. For same reason, hull is faired back aft to single huge, 15-ton five-bladed prop instead of the usual twin screws. Likewise bow diving planes have been moved up on "sail" (conning tower). Range, given as "more than 60,000 miles," is probably much more. Lt. Cmdr. William W. Behrens Jr., Skipjack's master, organized and was director of Nuclear Power School at New London Submarine Base

'Savannah' Keel Laid

A nuclear-propelled ship for commercial merchant service—world's first—passed from the paper stage to the steel stage last month with the laying down of a 60-ton keel section on a building ways at New York Shipbuilding Corp., Camden, N. J. This start on the 11,850-ton N.S. *Savannah*, highlighting observance on May 22 of National Maritime Day, came over three years after construction of the ship was first proposed; it came at a time when the vision of a large and varied nuclear merchant fleet began to loom as a real possibility for the near future (*see p. 20*). The $40.25-million joint project of AEC and the Maritime Administration (NU, Nov. '57, 78) will be powered by an advanced Babcock & Wilcox pressurized-water reactor, giving her a sustained speed of 20¼ knots and a cruising radius of 350,000 mi. She is scheduled to be launched one year to the day from the keel-laying, and to go to sea in 1960.

Westinghouse Gets 5 More Subs; Tullibee Laid Down

Westinghouse got Navy orders for reactors to power the Pittsburgh firm's 21st through 25th atomic submarines. The $17.9-million contract covers all five of the submarines originally asked of Congress in the Navy's 1959 shipbuilding program (the Navy is now understood to be asking seven instead of five). One of the five will be a missile-launching type (whether Regulus guided-missile or Polaris ballistic-missile has not yet been stated); the other four will be attack submarines of the *Skipjack* type. For the Navy, these five will increase the nuclear submarine fleet to 27. All will be Westinghouse-powered but *Triton*, General Electric, and *Tullibee*, Combustion Engineering; *Seawolf*, when she has burned out the core of her GE sodium reactors, is to get a Westinghouse water reactor.

Other nuclear navy news:

- Endurance records of 30 days and 31 days 5½ hrs were set by *Seawolf* and *Skate* on a cruise of more than 8,000 mi.
- *Tullibee*, the first hunter-killer submarine, had her keel laid at Electric Boat May 26.

U-Institute Hits AEC On Procurement Policies

Unimpressed by two recent AEC moves designed to mollify the uranium industry, the Uranium Institute of America last month accused the Commission of violating the Federal Administrative Procedures Act by failing to publish regulations covering the procurement of uranium.

Clearly in a belligerent mood, UIA executive vice president Gordon Weller complained to the Joint Committee on Atomic Energy that "many of the problems which the industry has experienced" could have been avoided by the establishment and publication of production goals by AEC. "Even at this late date," he added, "published procedures would be of great value to the industry."

Weller had this reserved comment about AEC's partial rescinding of the October 1957 moratorium on construction of new ore mills (NU, May '58, 24): "[It] recognizes the cases of hardship to a commendable degree, though not totally." Of last month's announcement of AEC permitting private sales to foreign and domestic buyers of U and U-concentrates, Weller said:

"These sales will mean a maximum of $16,000 per country in annual sales if the government price for the post-1962 period [$8/lb. U concentrate] is used as a guide. I doubt that the business will amount to more than $250,000 a year for the entire industry. This represents 1/10 of 1% of the present volume of business the industry is doing."

AEC spokesmen agreed with Weller that the announcement—authorizing U sales only to those countries with U. S. power reactor bilateral agreements—was not a new policy with respect to power reactors: that it was merely a public enunciation of a policy in effect for a year.

AEC also denied that it was violating the Administrative Procedures Act in refusing to publish regulations spelling out its U procurement policies. "Maybe we are but we don't think so," AEC commented.

Argonne Builds 2 Plants For Fuel-Making, Study

Two new plants for study and handling of plutonium and other nuclear metals now being built at Argonne National Laboratory—a $10-million Fuels Technology Center and a $4-million Fuels Fabrication Facility—will go a long way to hasten development of improved fuel cycles.

The Fuels Fabrication Facility has been underway for some time. The complex structure is completed, and installation of the specialized remote-handling equipment is proceeding. When ready for use in March 1959, the plant will be a complete fabrication shop for making any kind of object from plutonium or Pu alloys in controlled atmosphere. Rolling mills and other hazardous equipment will be automated, and all machine tools will be contained in some of the largest hoods and glove-boxes ever built.

First job for the facility will be to make the second core loading for EBR-2, the second experimental breeder in Idaho. The material to be used will be an alloy of natural uranium, 20% plutonium, and 8–10% "fissium,"—an artificial alloy made up of the elements found among fission products that are not removed by reprocessing: molybdenum, zirconium, ruthenium, technetium and palladium. Inserting these materials, cold, not only provides a fuel material reasonably close to what will be recycled in EBR-2: it also happens they contribute metallurgically useful properties.

Besides fuel elements, the facility will be able to make test pieces, zero-power plates, foils—"anything reactor engineers, chemists or chemical engineers want in the way of test objects." But it needs backup on structure, properties, behavior of materials. This will come from:

Fuels Technology Center, a research facility designed primarily for physical metallurgy research—not only on plutonium but also other metals of nuclear interest. The 220,000 sq ft building will be started this summer for completion early in 1960. Versatility will be the keynote of the center's capability. "We have to do a tremendous number of things to find out what we should be doing," explains Frank G. Foote, head of Argonne's metallurgy division. "So we need versatility—the ability to carry out almost any sort of research that may be indicated by research and development studies." In addition to standard lab equipment, hooded or glove-boxed, the Center will provide fine measurement apparatus, small vacuum and resistance furnace, and moderately large foundry and fabrication areas.

Joint Chiefs Ask More Pu, Anderson Sees 'Bail-Out'

The Democratic majority of the Joint Committee on Atomic Energy found a powerful ally last month in its fight for a substantial increase in the production of plutonium—the Joint Chiefs of Staff.

With at least tacit support of JCS the Democrats, led by Sen. Clinton P. Anderson (D-N. M.), looked to AEC's fiscal 1959 authorization bill as the vehicle to force at least one Pu reactor into the AEC construction program. The Joint Chiefs, Anderson revealed, told the Secretary of Defense in 1956, 1957 and again this year that they need a "substantial increase" in Pu production.

However, the Democrats face formidable opposition unless the Administration has a change of heart. The Department of Defense, of which JCS is only a part, made it clear to a JCAE subcommitee headed by Sen. Henry Jackson (D.—Wash.) that the military will get as much Pu as it needs over the next three years and that three years is as far ahead as the Pentagon will plan; the Budget Bureau turned down AEC's request for a Pu reactor in the '59 program because of the Pentagon's position.

Standing on tenuous middleground was AEC, which earlier this year indicated to JCAE that a reactor would be in the '59 program, then made this explanation when its '59 authorization request for plant and equipment failed to include the reactor: "We were advised on April 16 that as of that time there was no military requirement for addition to the existing production facilities."

In a speech to the Washington press corps, Senator Anderson said the AEC-JCS contradiction was one of two involving Pu. He asked why AEC was proposing a longterm Pu buyback program in the U. S. and abroad "if there was no military requirement" for more of the weapons material.

"Various reasons have been advanced for and against the buyback proposal," he said. "I speak only for myself, but I look upon it as a desperate effort to bail out the lagging foreign and domestic private atomic power programs."

The buyback plan was included in the request to Congress in January to permit the Administration to furnish more weapons information to the North Atlantic Treaty Organization. Authorization for the overall request is still under consideration by Congress but the buyback proposal was temporarily withdrawn by AEC in March.

Before AEC withdrew the proposal, Anderson declared, it had testified it planned to buy 11,000 kg of Pu from the NATO nations over the next ten years "at a weapons price of $30/gm," or a total outlay of $330-million. It was also brought out, he said, that the material could probably be purchased near the fuel-grade price of $12/gm but the premium was felt necessary to stimulate reactor construction abroad.

"This country, therefore," he charged, "would be paying an extra $200-million for Pu. . . . "

Anderson left little doubt what the Democratic strategy will be when the Pu reactor question is debated in Congress this summer. They will use the buyback plan, supported by the demands of the Joint Chiefs, to argue 1. that there is a clear need for the weapons material in the U. S., and 2. that the Administration is willing to pay several hundred million dollars for it—the equivalent of one or more reactors.

Meanwhile, NUCLEONICS learned that Senator Jackson, whose JCAE subcommittee on weapons has been holding closed-door hearings on Pu supply, has asked a four-man panel to sit in on the hearings and file a report early in June. The panel includes Gordon Dean, former AEC commissioner; John Lampe, North Carolina Univ.; J. Kenneth Mansfield, Combustion Engineering; and John Wheeler, Princeton.

Vessels Unlimited—Fast Breeding, Seagoing

92-ton reactor vessel (left) for Fermi fast breeder reactor shown just prior to leaving its birthplace, Combustion Engineering shops at Chattanooga, for 1,600-mi trip by barge and rail to Lagoona Beach, Mich., plant site. Trip down Tennessee and up Ohio rivers and over five rail lines cost $45,278. Core will be located in bottom section (partially hidden by stand); molten sodium will enter at bottom and flow up through the largest cylinder, the fuel-handling section; small cylinder at left is transfer rotor container; rotating plug assembly will be in neck of vessel at top

Parts of at least thirteen reactor vessels show in overall view (below) of Combustion's 520-ft long Chattanooga shops. Fermi vessel is seen at (A); others are pressurized-water reactor vessels for Navy. One (B) is seen spinning on a boring mill. Small vessel (C) may be S1C small-submarine prototype vessel; large one, nearly completed (D), may be for cruiser

Progress on First Four British Nuclear Plants 'Spectacular'; All Reported on Schedule Despite Big Problems

LONDON

Spectacular progress is being maintained on all four nuclear power station sites in Britain's atomic power program in spite of the many unusual welding and fabrication problems experienced. All projects are reported to be maintaining the extremely tight schedules set, and are even ahead of schedule on some of the civil engineering work.

Outstanding advances have been made in site welding and fabrication techniques associated with thick-skinned pressure vessels, the reactors being generally made in 3-in. thick boiler plate. Unusual lifting tackle, developed to handle prefabricated elements weighing up to 200 tons each and requiring large lifts, includes goliath cranes which are considered the most outstanding piece of construction equipment ever built in Britain. These are able to straddle a completed reactor and have lifting capacities of 200 or 350 tons.

All the consortia maintain that cooperation between contractors and the enthusiasm shown by everyone involved, quite surpasses anything previously experienced. What few labor difficulties have arisen, they say, have been quickly smoothed out. To date, no material bottlenecks have appeared and as far as this first round of stations is concerned, none are expected.

BRADWELL

Nuclear Power Plant Co.
300 Mw(e). Completion late 1960.

At Bradwell where first sod moved January 1957, the biological shield walls of the first reactor are complete to the top of their cylindrical portion. Construction of the outer parts of the shield-walls, fuel and control face building has to wait until all the pressure vessel sections have been installed in the reactor.

Boiler plinths have already been cast. The first of the 12 boiler shells was launched this month and towed 277 miles around the coast from the makers' works at Thornaby-on-Tees to the site. The decision to use this novel method of transportation was taken because each vessel would otherwise have had to been moved piecemeal to the site. A special landing dock has been constructed to enable the shell to be floated onto a low loading trolley at low tide which will be used to transport it the short distance to the site. It will be lifted onto its plinth by the 200-ton goliath crane which has now been completed and tested.

The shell was electrically stress-relieved as a complete unit, and after pressure testing was internally cleaned to a high standard using a new vacuum shotblasting technique. Each vessel is 19 ft dia, 92 ft long and weighs 200 tons.

The pressure vessel is being constructed in rings, each of 200 tons, so that the maximum amount of welding can be done remotely. Each ring is lifted into place by the goliath crane and joined by manual welding. The first two rings and the graphite support grid have already been completed.

Structures for the gas circulators are being constructed and erection of the first gas circulator unit has started. Turbine house foundations are complete, over half the structural steel work erected and cladding and brick work have started. The first turbogenerator is due for installation this year.

A recently-completed graphite machine shop with the latest machining and handling facilities is now producing the bottom reflector bricks for the first core.

BERKELEY

A.E.I.–John Thompson Co.
275 Mw(e). Completion late 1960.

Of the skyline transformations occurring at all four isolated nuclear sites, the most dramatic is at Berkeley. One reactor, with the core diagrid [core bottom support] installed, has reached the top dome; the concrete biological shield is within a few feet of the roof slab; two of the boilers have been erected, and cladding and glazing of the turbine house is well advanced.

The boilers, being fabricated in site workshops, will be placed from now on at monthly intervals. Civil engineering work on the cooling ponds, cooling water pumphouse and the intake works on the Severn estuary are ahead of schedule, and turbine mounting blocks are also well ahead of the scheduled installation date this year. Conventional lifting tackle has been utilized.

HUNTERSTON

G.E.C.–Simon Carves
320 Mw(e). Completion ~ 1961.

At Hunterston, permission to begin permanent work was not granted until October last year due to protracted opposition to the site. Rapid progress has since been made and the construction program is back again on its original schedule. Foundations for the first spherical reactor (NU, May '58, 108) have been completed and work on shielding started. Excavation on the turbine site is complete; foundation work there and excavation for the second reactor are proceeding.

The site is situated on rock. Blasting and excavation to level and remove faults was followed by mass concreting for each reactor foundation. Some 3,000 cu yd were poured, followed by the laying of a 8,000 cu yd concrete raft.

A complete workshop and prefabrication apron now nearing completion will enable civil engineering work to continue unhindered by work on the main steel structures. The building, which is served by two 40-ton traveling cranes, will be able to assemble simultaneously four steam raising units, each 80 ft long and 20 ft dia. Prefabrication of the six tiers of each 70-ft dia spherical reactor vessel will proceed on the apron in front of the building. A goliath crane, which will be used to raise the heat-exchangers and pressure-vessel sections, can straddle these construction areas and the reactors. The crane has a height and span each of 200 ft, can straddle a completed reactor building and lift up to 350 tons.

HINKLEY POINT

English Electric–Babcock & Wilcox–Taylor Woodrow
500 Mw(e). Completion 1962.

Good progress is also being made at Hinkley Point, Somerset, which is the latest and largest station in the nuclear power program.

Major earth stripping and moving operations on the reactor sites have already been completed. By mid-April work on the concrete foundations of the first reactor was complete. Construction of the 90 ft high, 75 ft dia biological shields started in April.

Work has also started on a 3,000-ft mass-concrete sea wall which incorporates the circulating cooling water pump house. Extensive site workshops have been built.

AEC Shucks Off Foreign Liability Issue

AEC, still working out regulations implementing the Price-Anderson indemnity law, has decided to steer clear of the foreign third-party liability question. It is also studying possible indemnification of contractors involved in weapons manufacture.

AEC believes it would be unwise to try to extend indemnity protection to U. S. firms operating overseas; instead, it is encouraging foreign governments to work up their own protection programs.

Industry Views to be Sought

Harold L. Price, AEC licensing chief, told the Joint Committee on Atomic Energy that industry comments on proposed indemnity regulations will be solicited soon, probably this month; public hearings will follow.

AEC has dropped its earlier plan to require $3-million minimum financial protection for any reactor indemnified by the government. Instead, small reactors will fall into several categories—a specific minimum for each.

Also, the rules as they are eventually proposed in tentative form will not include a fuel-cycle factor in computing protection for larger reactors. A fuel cycle factor had been under consideration by AEC (NU, May '58, 20).

Other Price Comments

Other highlights of Price's testimony:

- AEC has decided it can indemnify federal reactor operators other than itself under the indemnity law.
- State agencies which claim they cannot purchase insurance because of immunity against damage suits will be permitted to continue operating their reactors, pending enactment of federal and state legislation bringing them into compliance with the law.
- AEC contractors who have broader rights under previous contractual indemnities than permitted under Price-Anderson will get the benefits of both. Some contractors are covered for losses resulting from non-nuclear accidents, as well as accidents occurring outside the U. S.
- AEC is considering a requirement that applicants for reactor licenses prove they have picked the best available reactor site and/or submit alternate sites.

Atom Lobby Proposed; Industry Reaction Uncertain

The private atomic energy industry, spawned four years ago this summer in Washington, may celebrate its fourth birthday by forming a lobby in the shadow of Capitol Hill.

Virtually on the eve of the 1954 Atomic Energy Act's fourth anniversary, an invitation to join the Nuclear Industries Association of America, Inc., went out last month to some 350 members of the nuclear industry. It was signed by NIAA's executive secretary, Nelson (Pete) Jackson, attorney, former Air Force colonel, and Washington representative of General Electric's atomic operations until a few months ago.

"At the suggestion of several interested manufacturers who believe the time has come for the establishment of a nuclear trade association, and having discussed its need and merits with other people in industry, on the Hill, and in the Atomic Energy Commission, I have incorporated a non-profit organization in the District of Columbia. . . ." Jackson wrote. "When there has been sufficient response to this letter, an organizational meeting will be held in Washington of those manufacturers expressing interest."

Forum Rivalry Disclaimed

Jackson took pains in his formal invitation to disclaim any intent to compete with the Atomic Industrial Forum "in the useful and necessary functions [it] performs so excellently." The Forum, headquartered in New York City, has no Washington office.

Apparently anticipating a Forum cold-shoulder, Jackson worded a slight needle into his letter, then quickly extended an olive branch:

"The plan," he said, "is for NIAA to operate strictly as a trade association in the administrative and legislative problems of the industry which the Forum, with its heterogeneous membership in the U. S. and abroad, was not set up to do and should not attempt. As most members of the NIAA will also be members of the Forum, annual meetings might well be held in conjunction with the Forum's annual meetings as have been those of the American Nuclear Society."

Jackson also emphasized that NIAA would be primarily a manufacturers' trade association. There would be affiliate memberships available, however, to "users and others who may be interested in keeping up-to-date," the letter stipulated.

Jackson outlined the possible scope of NIAA in a 7-point list:

1. **Government-Industry Liaison.** To foster a government-industry relationship directed toward the development, at the lowest possible cost and with the least effort and delay, of the most advanced commercial and military products required by the nation.
2. **Coordination of Industry Activities.** To coordinate engineering, manufacturing, inspection and administrative activities of the nuclear industry in areas where cooperative endeavor or uniformity of procedures and processes contributes to productivity and efficiency of individual members.
3. **Interchange of Information.** To promote, through exchange of ideas and information, the solution to the industry's problems; and to keep the industry advised of government trends and regulations affecting design, performance, manufacture, procurement and licensing of nuclear products.
4. **Representation of Industry Policies.** To help establish policies and standards leading to the most efficient and economical industry practices, and to promote the recognition and application of such policies with cognizant government agencies and other organizations.
5. **Assistance to Government.** To serve and assist civil and military agencies of the government in the development of policies, standards and regulations for nuclear products.
6. **Cooperation with Users.** To work out solutions to common problems with users and others.
7. **Information to the Public.** To inform the branches of government, other industry, the press and the public regarding the accomplishments and problems of the nuclear industry. . . .

Should NIAA take hold, its coexistence with the Forum in New York and those utility trade associations lobbying on the power aspects of nuclear energy in Washington would parallel a similar set-up in the oil industry. Oil has a powerful multi-committee trade association concerned primarily with technological advancement of the industry as a whole—the American Petroleum Institute. API, like the Forum, is headquartered in New York; major segments of the industry with special marketing or other interests have their own lobbying groups.

Reactor News

WOLVERINE LONG ILL, SUCCUMBS

The Wolverine Electric Cooperative project for a 10-Mw(e) homogeneous reactor in central Michigan died May 16. AEC announced that day its conclusion "on the basis of recent studies that there is little or no early economic promise for [such] a small aqueous homogeneous power reactor . . . and that it would therefore be in the best interests of the government and of Wolverine to discontinue any further action with respect to the proposed project." A detailed cost analysis done for AEC showed that "cost of generating electricity from the proposed plant would be several times as great as Wolverine's present cost. Furthermore, it is apparent that the prospects are unlikely of reducing capital costs to any significant degree." The Wolverine project was based on Foster Wheeler's offer to build the reactor for $5.5-million, and began to founder last September (NU, Oct. '57, 19) when FW said it couldn't build it for less than $14.4-million. AEC said its action on Wolverine "would not affect its efforts and plans" on HRE-2 and PAR (the only other aqueous homogeneous reactors being operated or developed), explaining that on those two "the work is directed toward larger systems on which auxiliary equipment costs will not represent such a large percentage of total costs."

PIQUA, ELK RIVER CONTRACT TERMS SET . . .

"Agreement on the basis for contractual arrangements" covering small power reactors for Elk River, Minn., and Piqua, Ohio, were announced by AEC. ACF Industries is to build the 22-Mw(e) boiling water reactor for Elk River (15 Mw from the core of thorium and uranium oxides, 7 Mw from an oil-fired superheater); AEC would contribute $11.45-million to the project, including operating costs as well as ACF's $9,269,000 ceiling cost for development, construction, training and test-operation. The reactor would be completed by October 1960. Atomics International will build the 12.5-Mw(e) organic-moderated reactor for Piqua; AEC would pay $12.3-million research-development, construction, training and operating costs. This reactor would be completed by July 1961. Both would remain government property, as required by the new ground rules for aid to publicly-owned utilities set by Congress last year (NU, Sept. '57, 21) under which AEC deals separately with the utility concerning site, turbogenerator and operation of the entire plant, and with an equipment manufacturer regarding reactor construction.

. . . AND CAROLINAS-VIRGINIA ALSO

Hard on the heels of Elk River and Piqua, Carolinas-Virginia Nuclear Power Associates became the third small nuclear power plant to reach agreement with AEC on contract terms. All three were approved by JCAE, which waived the waiting period. The 17-Mw(e) Westinghouse heavy-water pressure-tube reactor 25 mi north of Columbia, S. C., at Parr Shoals (NU, Oct. '57, 25), would cost $34,655,000, of which CVNPA would pay $22-million capital costs and AEC $14.65-million in research-development and fuel use waiver. Last fall the capital cost was estimated at $17-million. The terms were negotiated in what may be the record time of one month since AEC accepted the proposal as basis for negotiation (NU, May '58, 26).

EBWR TURBINE RADIOACTIVITY VERY LOW

In spite of EBWR having been run for a week at 20-Mw(th) with a "deliberately impaired" fuel sample, the activity level inside the turbine right after shutdown was only 2 mr-hr (current exposure limit is 3,000 mr per three months). Unrelatedly, a turbine blade was found to have broken but did miraculously little damage; repairs are being done routinely, since activity permits.

BECHTEL GETS NEBRASKA CONSUMERS JOB

AEC has selected Bechtel as architect-engineer for the 75-Mw(e) sodium graphite reactor (SGR) being built by AEC and Consumers Public Power District. Earlier this year, Bechtel got the architect-engineer contract for PG&E's Humboldt Bay reactor. Atomics International, operator of AEC's Sodium Reactor Experiment (SRE), will build SGR, a tenfold scale-up of SRE. Expected to be completed by late 1962, SGR will cost $29-million—all but $5.2-million to be paid by AEC.

AEC JOGGING SODIUM COMPONENT EFFORT

A series of development contracts looking toward improvement of nonnuclear components for sodium reactor systems is under consideration by AEC. An invitation to industry to submit contract proposals went out May 8; deadline was May 26. AEC and private firms working on sodium systems have found that pumps, heat exchangers and other conventional equipment must be custom-made to cope with sodium's corrosion problems. AEC hopes to attract conventional component firms.

CURTISS-WRIGHT REACTOR GOES CRITICAL

Curtiss-Wright's 1-Mw swimming-pool research reactor, licensed by AEC April 28, went critical the next day. Designed and built by C-W, the Quehanna, Pa., facility cost $2.6-million, including five hot cells; it is capable of going to 5 Mw with a heat exchanger.

PG&E SAYS 8-MILL FIGURE CONSERVATIVE

Spokesmen for Pacific Gas & Electric told NUCLEONICS the firm's engineers "have done everything they possibly can to be conservative" in estimating the cost of electricity from the 60-Mw(e) boiling-water reactor to be built at Humboldt Bay, Cal. (NU, Mar. '58, 17). The $20-million unit is expected to produce 8.7-mill power with its first core, according to PG&E, and 8.1-mill with its second core, assuming a $30/gm plutonium credit. Based on core life of 15,000 Mwd/ton (470-million kwh annually at 90% load factor), the figures break down this way: first core, 2.8 mills for fuel, 4.9 mills for fixed charges including amortization, and 1 mill for nuclear insurance, operation and maintenance; second core, 2.2 mills for fuel, no change in others. Each core will use $5-million worth of 2% enriched U; fabrication cost is an estimated $2.8-million for the first; $1.86-million for the second. GE is guaranteeing 10,000-Mwd minimum burnup.

NEW CLADDING DEVELOPED AT ARGONNE

Argonne National Laboratory has developed an aluminum alloy which it expects to help reduce the cost of fuel elements. Developed for the Army's Argonne Low Power Reactor (ALPR) now under construction, the cladding alloy was perfected by adding small amounts of nickel to aluminum 1100, a commercial alloy containing iron. Dubbed Alloy X-8001, the material is rated much more resistant to hot water than other Al alloys. It is also held cheaper and easier to handle than zirconium.

ROUNDUP

World News

Austria Buys First Reactor from AMF

A 5-Mw pool research reactor has been ordered from AMF for the nuclear research center of the Austrian Study Group for Atomic Energy near Vienna. It is to be completed in December 1959. The Group (NU, Feb. '56, 15), a joint government-industry organization, will also install a 5.5-Mev Van de Graaff, hot cells and varied labs. For AMF it is the 15th reactor sale.

Test Reactor at Dounreay Critical

DMTR—Dounreay Materials Testing Reactor (NU, Oct. '57, 26), a Pluto-type 10-Mw(th) heavy-water unit, went critical late last month, first of three at that site to do so. The big sphere-enclosed fast breeder and a submarine prototype are still under construction.

NRU Knocked Out by Freak Accident

The $57-million NRU, highest-flux research reactor in the West (NU, Dec. '57, 25; April '58, 27) was put out of action for 3–4 weeks on May 26. It was shut down for removal of a defective uranium rod, which caught fire after removal; the fire was quickly extinguished but meanwhile radioactive dust had spread through the interior of the building. No one was injured.

Japanese, British Disagree on Earthquake Problem

A special committee named by the Japanese AEC has reported that it has been unable to reach agreement with a British team on the vital question of building an earthquake version of the Calder Hall reactor. After extensive study on both sides, the committee said, the crux of the problem remains "how to secure both complete safety and satisfactory performance of reactors in spite of frequent earthquakes in Japan". . . . The earthquake impasse may be a major reason why Japan has failed to initial a power bilateral with the U. K. despite the announced intention to order a power reactor this summer. A bilateral between Japan and the U. S. has been initialed by both governments and awaits ratification at a summer session of the Japanese Diet.

U. S. Atom Mission Attends Sydney Symposium

Taking part in Australia's nuclear symposium June 2–6 in Sydney was an 8-man U. S. mission headed by Clark C. Vogel, AEC. The mission was expected to discuss possible extension of the U. S.-Australian bilateral. . . . Atomics International was the only U. S. nuclear firm exhibiting at the symposium.

U. S., British Firms Bid for Spanish Reactor

Several U. S. and British reactor firms have filed bids to supply Spain with its first power reactor—a 20-kw(e) unit 35 miles outside of Madrid. Among the U. S. bidders are GE, Westinghouse and Internuclear; GE's boiling-water concept is reported to have the inside track.

Two British Partnerships Announced

New British industrial teams have been formed in two areas of nuclear energy—nuclear-propelled merchant ships and reactor instrumentation. The Nuclear Power Plant Co. has teamed up with one of Britain's leading shipbuilders—Swan Hunter and Wigham Richardson Ltd.—to form the nuclear-ship combination; the fourth British team in this field, they are prepared to handle both design and construction. Ekco Electronics Ltd. and George Kent Ltd. announced a formal instrumentation partnership after informal cooperation on four heavy-water reactors. Ekco will supply nuclear controls and health-monitoring systems; Kent the physical instrumentation and recorders for reactors, heat exchangers and turbines.

Notes on German Reactors, Fuel Supply

RWE, West Germany's huge utility firm, has received offers to build a 10–15-Mw(e) reactor from these firms: AEG (Allgemeine Elektrizitaetsgesellschaft); General Electric; Siemens/Westinghouse; Demag/Atomics International; Brown Boveri/Mitchell Engineering/General Nuclear Engineering; and ACF Industries. RWE has not abandoned its plans to buy a 250-Mw(e) reactor if it can be built at costs competitive with conventional stations (NU, Mar. '58, 26). . . . The consortium Brown Boveri/Krupp has completed development of a 15-Mw(e), thorium breeder reactor for AVR (Assn. of German Public Power Supply Companies). An order to construct is expected by late 1958; the breeder unit calls for graphite moderator, helium-neon cooling. . . . Canada has about completed shipment of 11 tons of U concentrate to Frankfurt for conversion to fuel-elements for the Karlsruhe research reactor.

India Rebuffs U. S. Reactor for British Unit

India's first nuclear power plant will be a Calder-Hall type, according to reports from Bombay. The Atomic Energy Establishment is said to have rejected a U. S.-designed package reactor because enriched-U purchases would drain dollar reserves. Time-table: a beginning on construction this year and completion by 1962 of a reactor supporting 100–150 Mw(e) of output. Estimated cost: $63-million.

Egypt Takes Delivery on Russian Reactor?

The German newspaper *Industrie Kurier* reported the delivery to Egypt of a Soviet reactor, presumably for research. Assembling of the unit, the paper said, awaits erection of its housing.

Czech Program Highlights Iron Curtain News

Czechoslavakia says it will begin building later this year the first of ten power reactors to be completed by 1970—5,000 Mw(e) total capacity. The first, capacity 150 Mw(e), will be located at Bohunice, some six miles east of Trnava in Slovakia. Estimated cost is one billion Czech crowns ($13-million), including research and development. . . . Moscow Radio reports Russian agreement to help Hungary build an experimental power reactor. . . . Yugoslavia's first reactor, also built with Russian help, was successfully tested last month.

U. S. Reactor Grants Go to Israel, Sweden

Helping Israel celebrate its tenth birthday, AEC authorized a $350,000 grant toward the cost of a 1-Mw pool reactor ordered from AMF Atomics; the research unit will be part of the $1,410,000 Israeli Nuclear Center. . . . AEC granted another $350,000 to Sweden to help buy a 30-Mw(th) tank-type research reactor from ACF Industries. Sweden is spending $4,294,995 for the reactor and auxiliary facilities, about half for the reactor itself.

News in Brief

AI Begins $1,250,000 Expansion Program
Atomics International is off to a running start on a six-building, $1,250,000 expansion program near the AEC-owned Sodium Reactor Experiment (SRE) at Santa Susana, Cal. Slated for completion in only six months, the operation includes a $500,000 experimental facility for study and test of reactor cores, a $240,000 laboratory for development of organic moderators, a $160,000 support lab for the SRE, and storage facilities.

M & C Nuclear Completes New Facility
An 11,200 sq ft laboratory addition to its Attleboro, Mass., plant has been completed by M & C Nuclear. The facility will be used to maintain "rigid production control of materials and to translate advanced technological methods into production processes" for nuclear fuel. M & C produces fuel elements, reactor cores and core components.

Union Carbide Stretches Out Building Program
Union Carbide, modifying the research program originally worked out for Sterling Forest, has deferred construction of the center's two nuclear units—a building to house the research reactor ordered from AMF and a "hot" lab. The center's other units are going ahead on schedule: a research-and-administration building, a minerals lab and a utilities building.

Hanford Plans $150,000 Isotope Plant . . .
A $150,000 pilot plant for the processing and packaging of radioactive by-products of plutonium production is planned at Hanford, Wash., by AEC and its operator there, GE. Initially, Hanford will concentrate on the development of remote control equipment for packaging, using nonradioactive materials; experiments with radioactive materials will not get started until early 1959. Hanford has contracted with Arthur D. Little, Inc., to conduct a year-long comprehensive study of the market for cobalt-60, cesium-137 and other radioactive by-products.

. . . Other Radioisotope Developments
Tracerlab has been issued the first AEC license covering decontamination and storage of waste by-product materials. The license covers the firm's facilities at Richmond, Cal., Waltham, Mass., and Houston, Tex. . . . Basic research work in the application of radioactive tracers to metallurgical processes has begun at two stations of the U. S. Bureau of Mines—Salt Lake City and Reno. Initial bench work and eventual pilot plant operation will be aimed at improving the refining of iron, manganese, copper and other ores.

Highlights of Printed '202' Hearings
The printed record of Congress' annual "202" hearings on the state of the atom—something of a sequel to the hearings held in February and March (NU, Apr. '58, 17; Mar. '58, 17)—showed several interesting items were filed later in writing: Herbert D. Vogel, chairman, Tennessee Valley Authority, told the Joint Committee on Atomic Energy that TVA has been discussing with AEC "arrangements which we believe would make our participation in the over-all [power] program more effective and provide substantial advantages to both the Commission and TVA." . . . R. W. Cook, deputy general manager of AEC, estimated that up to 2-million kw(e) capacity of U. S.-type power reactors would be in place abroad by 1964–65, excluding the U. K. . . . Rep. Chet Holifield (D-Cal.) warned Pacific Gas & Electric that it was prejudicing its case for "federal assistance in any form in the future" when it permitted AEC Chairman Strauss to announce its Humboldt Bay project during the first day of the 202 hearings. PG&E is handling the project without federal aid.

AEC Signs New Type of U Purchase Contract
Vanadium Corp. and AEC have worked out the first contract of its type in the history of AEC uranium buying. The agreement, running until March 31, 1962, includes these unique features: 1. states specific amounts of U concentrates for annual delivery; 2. makes no mention of ore input into Vanadium mills; and 3. runs for a relatively short period (some run through 1966).

Nuclear Pools Assuming Liability Coverage
Casualty insurance companies in the U. S. have begun to attach nuclear exclusion endorsements to conventional liability policies of atomic energy firms. Risks being excluded must be submitted to either the Mutual Atomic Energy Liability Underwriters or the Nuclear Energy Liability Insurance Association. Set up to cover nuclear risks, these two pools include more than 200 stock and mutual liability firms.

Two New Accelerators for Phillips Petroleum
A new accelerator building, housing a 10-mev electron linear accelerator and a Cockcroft-Walton positive-ion accelerator rated at 400 kv, has been projected for Phillips Petroleum's research center, Bartlesville, Okla. Both were purchased from Applied Radiation Corp., Walnut Creek, Cal., are slated for operation this year.

Thermocoupling Seen Promising in 10 Years
AEC reactor officials are optimistic about the application of thermocouples in the power reactor field, permitting the discard of conventional generating equipment. Thermocouples, it is felt, will become "a real factor in atomic power in less than ten years," though not in use until some time later. Significant progress, it is reported, has been made recently in developing materials with the proper thermoelectric characteristics to permit military and commercial use.

California Withdraws Hearing Demand on Disposal
Fish and Game officials of the State of California have agreed to withdraw their demand for an AEC hearing on further licensing of radioactive waste disposal off the state's coast. Formal airing of the protest has been waived temporarily pending the outcome of late May talks with AEC, officials of three firms already licensed, and a fourth now seeking a license.

Sporn Sees Power Atom Coming into Own in 1975
Philip Sporn, president of American Electric Power Co. (formerly American Gas and Electric), estimates that 5% of U. S. electrical capacity by 1975 will be nuclear; however, 25% of capacity added between 1975 and 1980 will be nuclear, he feels. He looks for only gradual improvements over the next 20 years but says they will add up to a major technical and economic achievement.

Cosmotron Contract Awarded to Burns & Roe
A design-engineer contract for the expansions at Brookhaven's 6-Bev Cosmotron has been awarded to Burns and Roe.

ROUNDUP

More About Our Curve

NUCLEONICS' work-in-progress curves (right) have been further refined this month. Last month's "federal funds" curve—including the nuclear Navy program—showed costs for the entire ships as cost figures for their propulsion plants alone were then unavailable. This month's adjusted curve has pared away cost of hull, armament, ship's services, etc., and includes only the propulsion plant costs proper.

Fields Resigns; Others May

A wave of AEC top leadership departures has the industry worried. General Manager Kenneth E. Fields announced he was leaving July 1 "or sooner" if a successor can be found; he gave no reason for quitting. His deputy, R. W. Cook, is also reported leaving. Reactor development chief W. Kenneth Davis is reported considering leaving AEC later this year; his deputy, Louis H. Roddis, has already resigned (NU, April '58, 19).

SRE Reaches Full Power

The Sodium Reactor Experiment, built and operated by Atomics International for AEC, reached design power level of 20-Mw(th) May 21, a year after it first went critical.

PWR Finally Dedicated

After more than five months of successful operation, the Shippingport PWR was formally dedicated May 28. President Eisenhower used a neutron source-wand to open the turbine throttle by remote control from Washington.

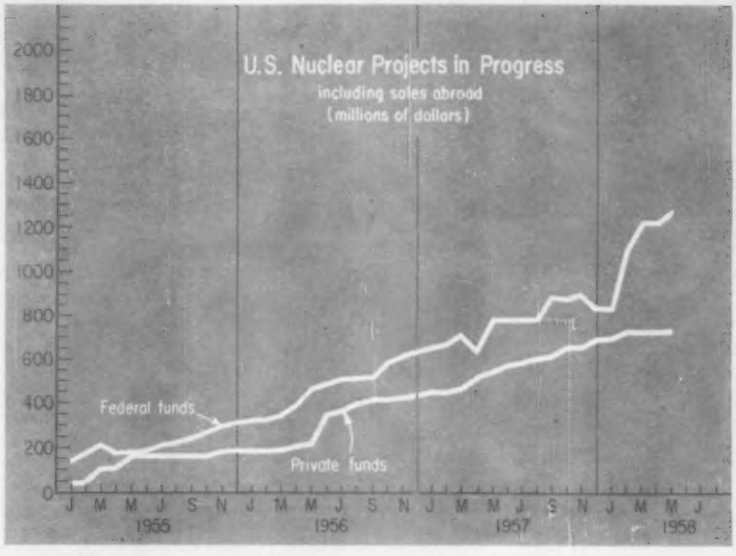
East Central Group Formed

Informally in existence for some time, the 12 utilities of the East Central Nuclear Group (listed, NU, Jan. '58, 17) incorporated last month. The non-profit group is working on two reactor projects: one with Florida West Coast Nuclear Group, and one with NDA (NU, Feb. '58, 24).

Radiation Panel for NYC

Mayor Wagner of the nation's biggest city named a Technical Advisory Committee on Radiation to cope with radiation questions. Headed by John C. Bugher, former AEC biology and medicine chief, the group will act as liaison between the Mayor and federal and state agencies. Hanson Blatz of AEC's Health and Safety Lab was named radiation consultant to the city's health department.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts*—			
Contracts awarded for federal projects ($10³)	2,842	20,407	10,515
Proposed construction, privately-owned ($10³)	0	0	17,000
Contracts awarded, private work ($10³)	13,660	3,500	120
Backlog of private projects ($10⁶)	268	269	193
Access Permits†—			
Access permits issued	16	24	34
Total access permit holders	1,410	1,411	1,281
Isotope Use†—			
Applications for isotope use	629	564	496
Cumulative total of isotope users	3,692	3,587	3,988
Oak Ridge National Laboratory shipments	1,267	1,300	1,288
Public and private export shipments	426	449	206
Employment†—			
AEC employment	6,881	6,831	6,646
Construction and design contractors' employment	10,059	9,973	14,782
Total operating contractors' employment	100,777	100,559	96,593
Production workers	50,703	50,516	50,745
Research and development employees	43,791	43,980	39,594
Miscellaneous workers	6,283	6,063	6,254

	Operating	Building	Contracted
U. S.-built Reactors‡—			
Power, domestic	1	5	9
Power, for export	0	1	2
Power experiments and pilot plants	7	4	1
Military and naval	5	22	11
Research and test, domestic	44	23	39
Research and test, for export	7	14	6
Foreign-built Reactors‡—			
Power, domestic	4	24	12
Power, for export	0	0	2
Research and test, domestic	28	14	8
Research and test, for export	4	8	1

* From *Construction Daily*, a McGraw-Hill periodical †From AEC ‡ NUCLEONICS figures

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SIX MONTH USER SURVEY

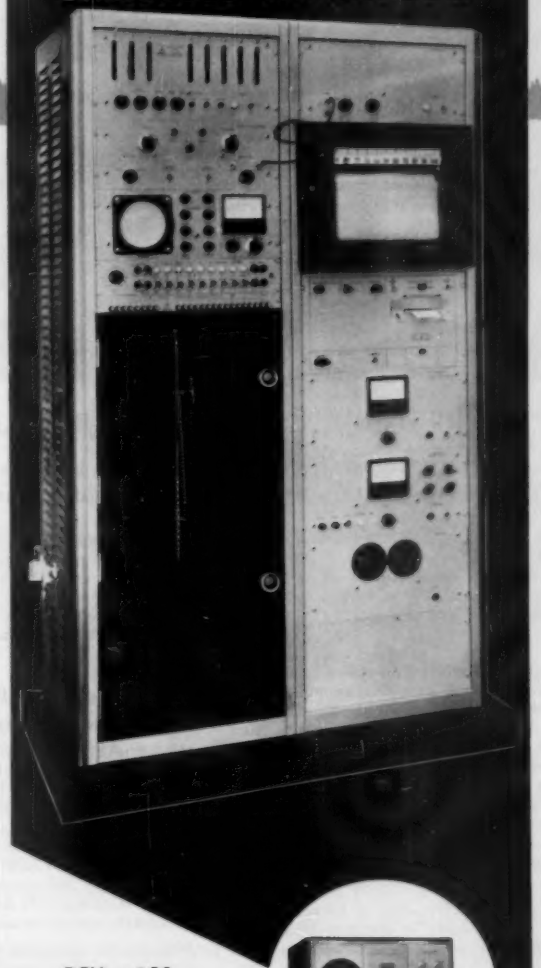
• We surveyed multi-channel analyzer users to find out what they wanted in an analyzer. The results of this survey, combined with our years of research and manufacturing experience in the multi-channel analyzer field, have enabled us to produce what we consider the finest analyzer on the market today—the improved RCL 256.

Our customers not only helped us develop the RCL 256 but also this ad—much of which is composed of excerpts from our survey of current RCL 256 users.

RCL

The improved

RCL 256
CHANNEL ANALYZER



Typical Uses of the RCL 256*

" . . . low level gamma counting . . . fission product and fallout analysis . . . alpha pulse spectrometry . . . X-ray absorption coefficient determinations . . . shielding evaluation . . . isotope identification . . . Mesonic X-ray energy measurement . . . Na^{24} and K^{42} spectra with a human source . . . neutron time-of-flight studies . . . recording coincidences between protons and electrons in neutron decay . . . investigation of gamma-ray spectra involved in proton capture . . . two crystal Compton coincidence gamma-ray spectra experiments . . . three crystal pair production gamma-ray spectra studies" . . . ad infinitum.

* Actually, uses of the RCL 256 are as numerous and varied as our customers. The RCL 256 may be the solution to your radiation measurement problems. For more information write or call RCL collect.

Improved RCL 256 Offers You These Advantages

Proven Reliability. The reliability of the RCL 256 is best attested to by its users. Over one-third of them now use more than one RCL 256. In fact, some laboratories use from four to ten RCL 256-Channel analyzers and consider them indispensable.

Pre-set Time to 27 Hours. Extremely reliable dead-time correction enables the RCL 256 to operate automatically from 100 seconds to 27 hours of "Live Time" (elapsed time less dead-time). When the RCL 256 is used in automatic pre-set time, the background may be counted for a period of "Live Time" equal to the original run and automatically subtracted from the original run data.

Fast Readout. All channels are printed out in one minute (five channels per second).

Logarithmic Readout on cathode ray tube and strip chart recorder. Completely transistorized log converter assures reliability.

Completely Integrated System. Scintillation high voltage supply and linear amplifier are built into the basic instrument.

Delivery within 30 to 60 Days.

Free Installation. To make certain your analyzer functions properly, RCL engineers install it for you. They also demonstrate and instruct you in the instrument's operating procedure.

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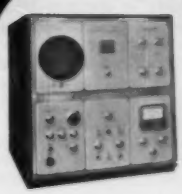
The RCL 256-Channel User survey containing analyzer uses, users' opinions, operating problems, suggestions for improvement etc. is available unedited. Find out what users think of the RCL 256-Channel Analyzer. Write RCL today for a free copy of the survey results.



RCLiac 128 Available in November

To scientists who desire the ultimate in reliability, which transistorization provides, we recommend the RCLiac 128. This combination scaler-analyzer performs every operation from gross counting through scintillation-spectroscopy. Numbers are presented on a cathode ray tube, making electro-mechanical printers unnecessary. Plug-in module construction precludes obsolescence.

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arco APPLIED RADIATION news

Linear electron accelerator for nuclear research

GA plans studies in power reactor design, neutron and solid state physics, nuclear and radiation chemistry

Intense neutron, x-ray and electron beams from a 2 to 32 Mev ARCO Mark 1-T4 linear electron accelerator will open another area of General Atomic's expanding program of nuclear research when the accelerator is installed this spring. GA physicists will use the (γ,f) and (γ,n) reactions in uranium to produce up to 10^{16} neutrons per second (peak rate during pulse) for research in neutron physics and for studies with sub-critical power reactor cores. Nuclear chemists will study photonuclear processes with precisely controlled bremsstrahlung of the order of 5000 times as intense as has been attainable with betatrons and synchrotrons. The accelerator's pulsed electron and x-ray beam will also be used for fundamental investigations in solid state physics and radiation chemistry.

General Atomic Division of General Dynamics Corporation is the corporate unit responsible for research, development, and production in the nuclear field. Its new John Jay Hopkins Laboratory for Pure and Applied Science in northern San Diego is conducting research in reactors, nuclear and solid state physics, chemistry, and controlled thermonuclear reactions. A source of radiation was needed which would meet the diverse demands of the Laboratory.

General Atomic chose an ARCO Mark 1-T4 linear electron accelerator. Initially operable at energies continuously variable to 32.5 Mev with electron beam power to 4 kilowatts, this accelerator is designed for subsequent 2-fold expansion in both power and energy.

For Neutron Physics—10^{16} Neutrons/Second during Pulse

High energy photofission reactions in uranium are among the most efficient neutron-producing reactions. High energy linear accelerators are intense x-ray generators and hence are useful sources of fast neutrons. General Atomic's ARCO Mark 1-T4 linear accelerator will produce neutrons at a rate of 10^{16} per second during pulses of ½ to 5 microseconds duration; it will generate average yields of 10^{12} per second.

Photofission reactions yield a characteristic fission neutron energy spectrum; monoenergetic neutrons will be obtained by time-of-flight techniques. General Atomic plans to measure neutron cross-sections as well as detailed parameters characteristic of sub-critical reactor systems such as neutron spectra, diffusion constants, and neutron lifetimes.

For Nuclear Chemistry—Gamma Yields 5000 Times Greater than from a Betatron

Both the efficiency of bremsstrahlung production and the average energy of the bremsstrahlung spectrum increase with the energy of the primary electron beam. High beam power allows magnetic energy analysis to within 0.1-0.01 percent for precise bremsstrahlung generation. General Atomic's nuclear chemists plan fundamental investigations of (γ,n), (γ,p), (γ,α), (γ,d) and (γ,f) reactions as well as processes induced by neutrons. Photonuclear reactions will also be utilized for activation analysis and the production of nuclides which cannot be produced in a reactor.

For Solid State Physics—½ to 5 Microsecond Electron Pulses

General Atomic will utilize the accelerator's pulsed electron and x-ray beams to study both transient and gross radiation damage in semiconductors and structural materials. Electrons with energies of a few million volts will produce isolated interstitials and vacancies. With full machine energy, atoms knocked out of the lattice by a direct bombarding electron hit will have sufficient momentum to displace about ten other atoms. Thus, more complicated forms of radiation damage can be studied.

For Radiation Chemistry—High Intensity, Deep Penetration

G.A.'s pulsed electron beam will permit study of free radicals and other short-lived chemical species induced by ionizing radiation, for a sufficient number can be created in a single pulse or short series of pulses to allow direct identification. High beam energies make possible electron and x-ray irradiation of pressurized systems and thick specimens; high power operation makes study of low-yield reactions practical.

General Atomic plans to make time on its ARCO accelerator available to selected research and development organizations and users of radiation. It also will conduct contract research studies of interest to the Laboratory.

Write for Information

Applied Radiation Corporation specializes in the development and manufacture of electron and positive ion accelerators. Modular construction allows ARCO to tailor accelerators to the needs of individual organizations, whether modest or demanding.

Write for technical data on ARCO accelerators and reports, AM-105, *Isotope Production with a Linear Accelerator* and AM-100, *Production of Gamma Radiation with a Linear Electron Accelerator*. Department N-6.

ARCO APPLIED RADIATION CORPORATION

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For more information about PACECO's services and facilities write for Brochure 6-A

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LPTR now in operation . . .

Livermore Laboratory, Livermore, California. Photo courtesy of the A.E.C. and Foster-Wheeler Corp.

another reactor under L&N control

For the Atomic Energy Commission's 1000-kw Livermore Pool-Type Reactor in California, an integrated Leeds & Northrup control system was specified—a system bringing together all instruments needed to record and control nuclear functions at all power levels in this convenient console-cubicle. Among its many features, this instrument system:

• *provides the operator—by means of L&N Speedomax® recorders and indicators—with accurate information on conductivity in the tank, temperatures throughout the cycle, and area radioactivity.*

• *adjusts rod positions smoothly and automatically at operating levels through the proved P.A.T. Series 60 servo unit.*

• *uses standardized components skillfully assembled to meet specific requirements of the reactor, making possible maximum efficiency at reduced cost.*

Information on L&N's integrated control systems for research and power reactors is available in Folder ND46-03-268(1), from Leeds & Northrup Company, 4936 Stenton Avenue, Philadelphia 44, Penna.

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instruments *automatic controls* • *furnaces*

CN/Zr Tech Digest

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ZIRCONIUM

from Columbia-National

The new Columbia-National Zirconium Plant near Pensacola, Florida is the most modern in the world. The "Nitrophos" process continuously and automatically separates hafnium from zirconium and removes impurities, thus assuring uniform, high quality zirconium sponge.

The Zirconium Age has arrived! Columbia-National's new sponge plant now offers you a ready source of reactor and commercial grade zirconium.

Uniform high quality zirconium is assured by converting zircon sand to sponge at one location under the responsibility of one management. The unique "Nitrophos" extraction process separates and purifies zirconium and hafnium in this plant.

Reactor-grade and hafnium-containing commercial-grade zirconium sponge are available for government and industrial requirements. Leading metal converters and fabricators are now supplying zirconium mill and finished products.

There is new opportunity in the Zirconium Age. You are urged to investigate its use in atomic reactors and in process equipment where corrosion conditions are severe. Columbia-National is ready to help with melting, fabrication and application assistance. Write for technical bulletin, specifying your interest.

Illustration of typical reactor core courtesy Westinghouse Electric Corporation

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Ferrous, non-ferrous and titanium alloys give you the properties you need for positive performance.

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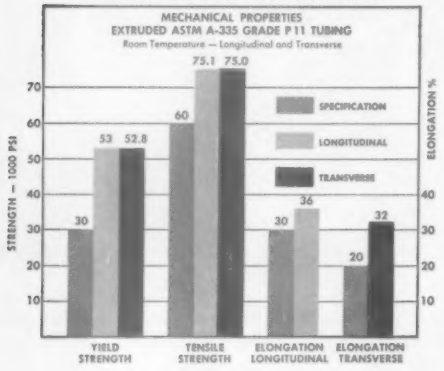
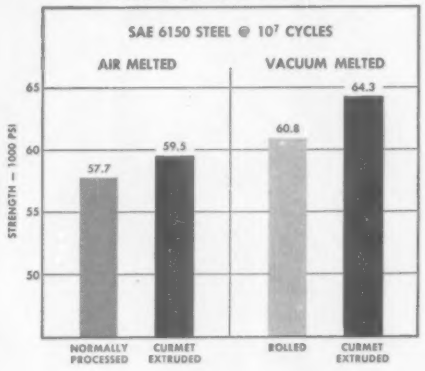
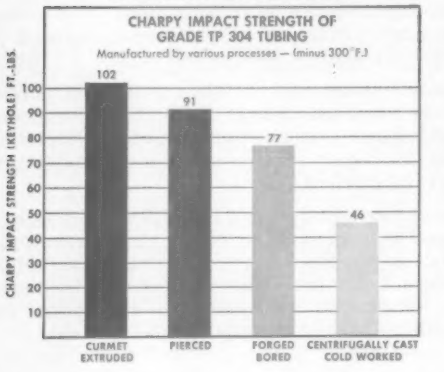


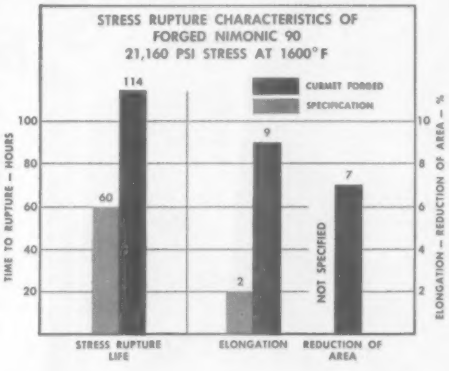
TORSIONAL FATIGUE



IMPACT STRENGTH



ELEVATED TEMPERATURE



Above are examples of physical properties resulting from CURMET Processing. Consult CURMET for data to meet your design problems. CURMET Processing has been developed by the Metals Processing Division of the Curtiss-Wright Corporation.

FOR FULL INFORMATION, WRITE TO:

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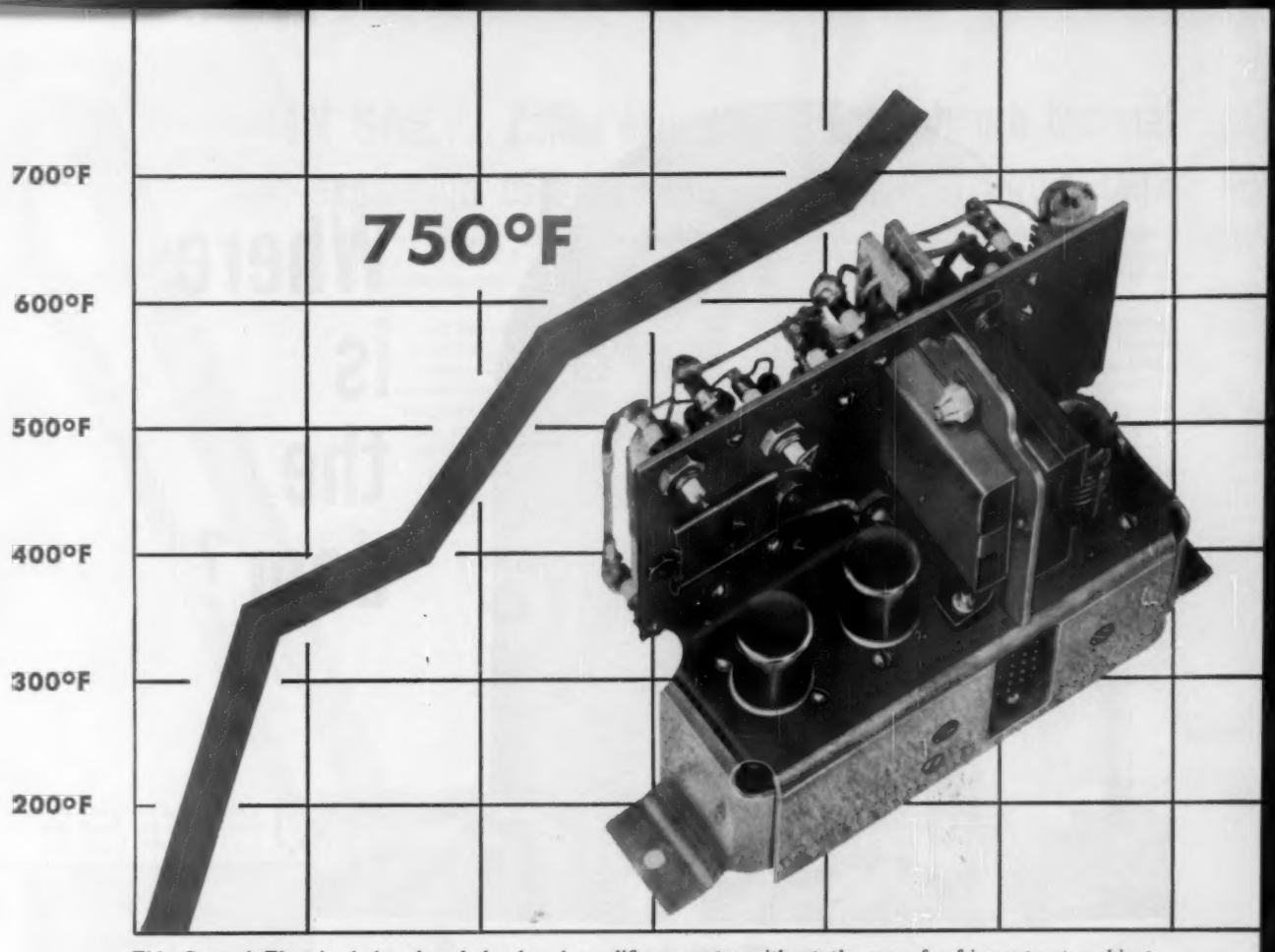

This General Electric designed and developed amplifier operates without the use of refrigerants at ambient temperatures from −67°F to 750°F.

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Here's important news for you if your systems project dictates the need for temperature and radiation tolerant electronic equipment. The General Electric Company stands ready to undertake the design, development, manufacture and evaluation of your equipment where your specifications call for successful operation up to 750°F, without refrigerants. And General Electric's ability to meet your high-temperature requirements is backed by notable successes.

FOR EXAMPLE General Electric has already developed airborne amplifiers which have been successfully operated over an ambient temperature range from −67°F to 750°F. Special circuit designs and packaging techniques permitted this without the use of heavy, complex refrigerating equipment.

FOR INFORMATION on how General Electric can help you solve your high-temperature electronic equipment problems, contact your G-E Missile and Ordnance Systems Department Field Sales Office or mail the coupon below.

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☐ Please send me bulletin MPB-32, "High-Temperature Electronic Equipment."

☐ I would appreciate a discussion of my equipment requirements with General Electric High-Temperature Engineering Specialists.

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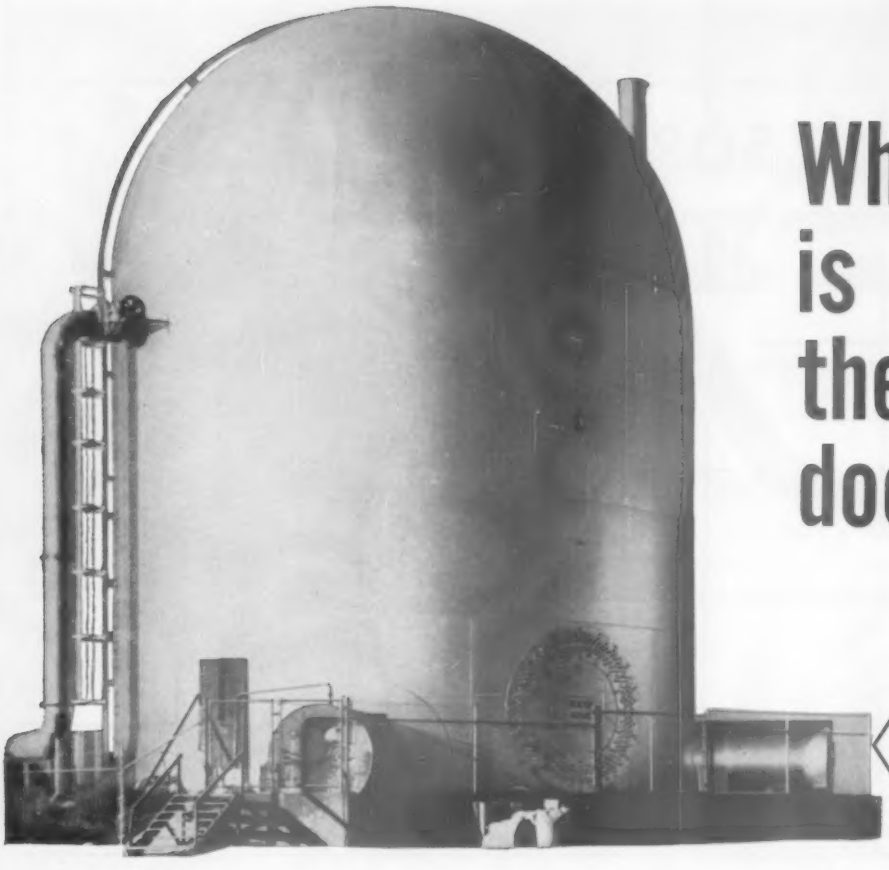

Where is the door?

These two tubular entrances are the Pratt Air Locks in the Vallecitos Boiling Water Reactor at the General Electric Vallecitos Atomic Laboratory at Pleasanton, California.

The Henry Pratt Personnel Air Lock

provides easy passage in and out of containment vessels in full compliance with the AEC code for reactor construction.

While the Air Locks are designed and built specifically for each atomic power plant, they all include some very desirable Pratt developments.

An interlocking feature that keeps one door shut while the other is open is typical of the many simple operating principles that add up to a high safety factor. Any arrangements of automatic and manual controls can be incorporated.

The locks can be built to withstand any practical pressure with compression or pneumatic door seals . . . size is no problem—locks are now being built that will accommodate trucks.

Air Locks already installed . . . Two locks in the Boiling Water Reactor of General Electric's Vallecitos Atomic Laboratory, Pleasanton, California . . . Two locks in the M.I.T. Research Reactor.

Air Locks now being built. . . Three locks for the C.N.R.N. Reactor, Ispra, Italy . . . One lock for the Enrico Fermi Atomic Power Plant of the Detroit Edison Co., Laguna Beach, Michigan . . . Two locks for the 30 MW Test Reactor at the General Electric Vallecitos Atomic Laboratory, Pleasanton, California.

Manufacturers of
Personnel Air Locks
Rubber Seat Butterfly Valves
Turbine-Condenser Expansion Joints
Paper Mill and Converting Equipment
Specialized Steel Fabrication

HENRY PRATT

One of the two Pratt Air Locks now in use at the M.I.T. Research Reactor.

Henry Pratt Company, 2222 S. Halsted St., Chicago 8, Ill. Representatives in principal cities

IN SRE... Zallea expansion joints absorb thermal expansion of reactor core tank and outer tank

The very nature of the Sodium Reactor Experiment, conducted by Atomics International for the AEC, and the method of handling the liquid sodium reactor coolant demand reliability in expansion joints. Because of the operation there can be no compromise in design or quality.

The high temperature SRE uses Zallea Expansion Joints where thermal expansion must be absorbed and where a gas seal must be maintained. An 11-ft. diameter Zallea Expansion Joint at the top of the outer tank absorbs the expansion that results from the temperature increase in these components as the reactor comes up to operating temperature, 960°F. In addition, the expansion joints form a seal for the helium gas and sodium vapor above the sodium pool at the top of the reactor as well as for the helium gas within the outer tank.

In the sodium coolant piping circuit gas seals are effected by means of Zallea Expansion Joints in the region where the pipes leave the reactor cavity and enter the pipe galleries.

Zallea has worked with almost every major engineering and manufacturing firm engaged in atomic, nuclear and missile work—and has provided the large majority of expansion joints for such projects. As a result, we have accumulated a store of expansion joint engineering data and manufacturing skills that cannot be equalled. Whenever expansion is involved in piping systems, reactors, tanks—whatever the application—let our engineers work with you. We already have the answer to many of the difficulties you will encounter. And we welcome the chance of tackling your problem.

Zallea
expansion joints

ZALLEA BROTHERS, Wilmington 99, Del. • World's largest manufacturer of expansion joints

rigid specifications

Tension tests are required to be made at room temperatures and at 670° F. The following minimum physical properties shall be met:

At Room Temperature:

TS	YS	EL	RA	CHARPY V-NOTCH
70,000	30,000	45	50	50

At 670° F. the minimum tensile strength shall be 51,000 p.s.i. and the minimum yield strength 18,300 p.s.i.

Rejection

Each casting that develops unacceptable defects during shop working or fails to conform to all of the requirements of these specifications shall be rejected. No repair by welding or other means will be permitted.

Radiographic Inspection

(a) Paragraph S5 (a) of the Supplementary requirements of ASTM-A 362-52T.

(b) All castings shall be radiographed 100% and shall conform to ASTM-E7 1-52, Class 2 quality, except as modified by these specifications.

(c) The manufacturer shall establish a positive system of identification of the X-ray plates which shall be subject to approval by the inspector. This system shall guarantee complete coverage by radiographing and provide for positive identification between the plate and the subject.

All cast pipe shall be hydrostatically tested to 5,900 p.s.i. and held at that pressure for 20 minutes with zero pipe leakage. Each length of pipe shall be hydrostatically tested at the manufacturer's plant.

Inspection of Penetrants

All castings shall be subjected to inspection by fluorescent penetrants or penetrating dyes both inside and out. All cracks, porosity, or flaws revealed as a result of the Dye Penetrant Test shall be due cause for rejection of the casting.

The 304L stainless steel shall conform to the following ladle analysis:

Carbon	.03 max.		
Manganese	1.50% max.		
Phosphorous	.03% max.		
Sulphur	.03% max.		
Silicon	2.00% max.		
Chromium	18.00	-	21.00%
Nickel	8.00	-	11.00%

Pipe: All pipe of the following sizes shall be centrifugally cast stainless steel as per ASTM-A 362-52T, except as modified by these specifications:

16" - Sch. #160
12" - Sch. #160
10" - Sch. #160
8" - Sch. #140

All pipe shall be machine finished to 125 micro-inch interior and exterior.

for nuclear piping met by U.S. PIPE metal mold process

Centrifugally Cast Stainless Steel Solves Many Piping Problems

Combinations of temperatures, pressures and corrosive conditions never encountered before: these are among the piping problems that must be overcome by the men who design the nation's nuclear power installations.

Stainless steel centrifugally cast pipe provides many of the answers. Study the specifications at the left . . . specifications demanded of stainless steel pipe on a recent job for Paul Hardeman, Inc., Los Angeles, California. This pipe is being used for heavy duty, high pressure, elevated temperature service in the primary piping system of the SPERT-III Reactor at the U.S. Atomic Energy Commission's National Reactor Testing Station near Idaho Falls, Idaho. The Stearns-Roger Mfg. Company, Denver, Colorado, is the architect-engineer on this project. A complete tabulation of the actual test data obtained on this pipe and to this specification is available upon request.

U.S. Pipe is headquarters for metal mold centrifugally cast alloy and stainless steel pressure pipe over a wide range of special and standard analyses—in large and small quantities—and to individual specifications.

If piping of the type described above is the bottleneck in your nuclear power planning, write and outline the problem.

SIZE RANGE AND COMPOSITION FLEXIBILITY

Outside Diameter—6" to 50"

Wall Thickness—⅜" and up

Length—Up to 16'

Types of Stainless—All Standard AISI and ACI grades of ferritic and austenitic stainless, including No. 20 Alloy, 17-4 P H, 17-7 P H and E.L.C. grades.

UNITED STATES PIPE & FOUNDRY CO.

Steel and Tubes Division

STEEL & TUBES U.S. PIPE DIVISION

BURLINGTON, NEW JERSEY

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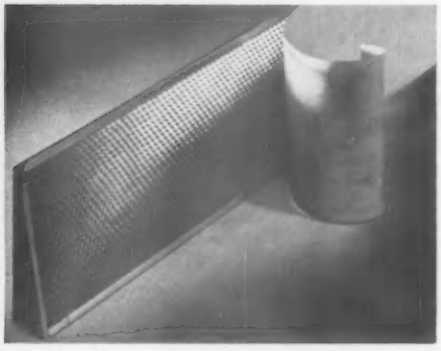
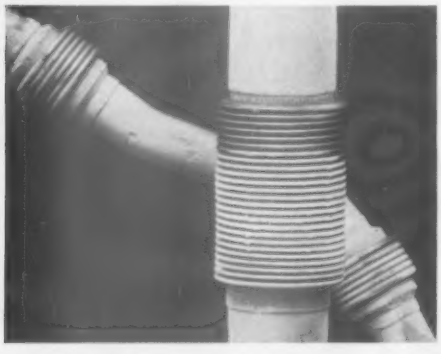
Special Solar Skills for Advanced Systems

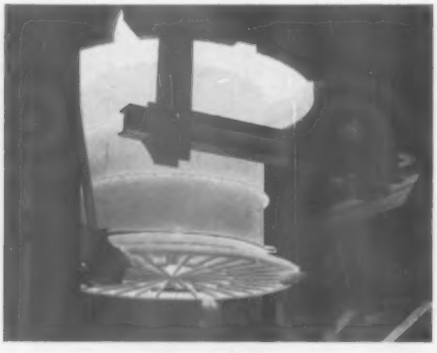


HIGH-TEMP. HONEYCOMB. Solite®—a lightweight, heat-resistant brazed steel, high alloy sandwich structure developed by Solar—has high potential for use in advanced systems.

PROTECTIVE COATINGS. Solar research and development in advanced metallurgy has produced a family of high-temperature protective coatings far ahead in the field.



EXPANSION JOINTS. Solar produces the largest array of expansion joints in the world, including complete ducting systems for aircraft, missile, nuclear and other applications.



HIGH-TEMP. BRAZING. Using hard-to-work metals and high-temperature alloys, Solar brazes stronger, lighter systems components in specially designed heat-treating furnaces.

Solar offers proven systems capabilities

Systems capabilities at Solar embrace the design, development and production of airframe, propulsion, ground support, guidance and control systems. Responsibility for Solar's systems program is centered in a team of experts experienced in the many sciences related to systems technology—from basic design to highly-precise experimental, prototype and volume production. And underlying Solar's systems capabilities is a backlog of more than thirty years of proven leadership in high-temperature metallurgy, aerodynamics, thermodynamics, combustion research and others.

Complete manufacturing and test facilities are also available for your important systems program. For detailed information about Solar's systems capabilities, or about any of the areas mentioned above, write to Dept. F-24, Solar Aircraft Company, San Diego 12, California.

SOLAR
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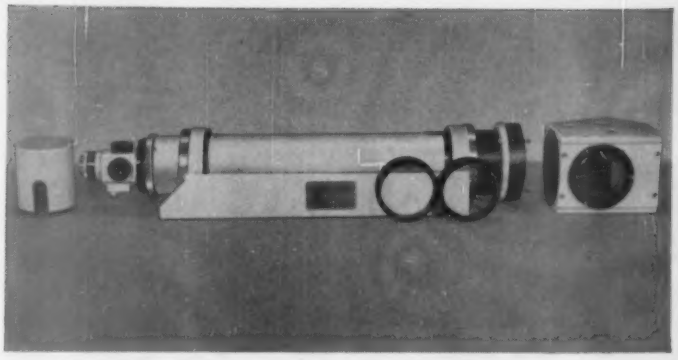
DES MOINES



Problem To align radar antennas with extreme accuracy.

Solution Kollmorgen 30X Collimator.
Measures within a pencil's width at a mile.

Problem Remote viewing in the presence of harmful radiation, heat, pressure, water or toxic gases.

Solution Kollmorgen Wall Periscopes with non-browning optics, corrosion-resistant materials, 180° scanning.

Kollmorgen instruments like these are bridges between the eye and the invisible.

The various instruments on this page all have one purpose in common—they allow the observation and measurement of objects which it would otherwise be impossible to see in detail. In bunkers, under water, in the absence of light, in the presence of radioactivity and under many other adverse conditions, Kollmorgen remote viewing instruments have brought the eye of the observer to the heart of his problem.

A letter to us with a simple sketch illustrating your remote viewing problem will place one of America's most respected and versatile designers and manufacturers of optical instruments at your service. For more information write Department 116.

Problem Detailed, long-range observation at sea under varying weather conditions.

Solution Kollmorgen 20X, 120 Ship Binocular. Wide, bright field. Hermetically sealed, super lightweight.

Problem Internal inspection of inaccessible areas of tubing, long bores, machinery, engines, aircraft structures.

Solution Zeiss-Kollmorgen Self-illuminating Borescopes. Diameters from .100", lengths to 45 feet. Bright, clear field.

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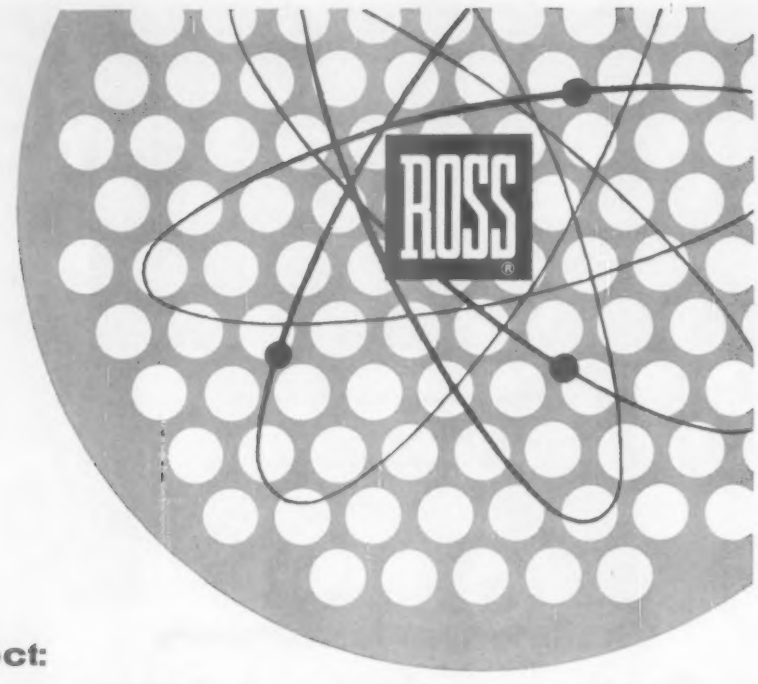
347 KING STREET, NORTHAMPTON, MASS.



On this subject:

HEAT EXCHANGERS FOR NUCLEAR SYSTEMS

. . . Ross speaks with experience

The initiative which Ross has taken in virtually every field of heat exchanger development applies to the nuclear energy field, as well. Ross engineers were early at work.

Starting with exchangers designed and fabricated for the Manhattan Project, and carrying on down right through to today, Ross has been steadily building its reputation in nucleonics circles.

The readiness of Ross to perform engineering development; the possession of the necessary skills to work with specialized materials; the ability accumulated through experience to meet stringent specifications; the opportunity to draw upon the vast resources of American-Standard* through its Atomic Energy Division . . . these and others are points which Ross engineers would be pleased to discuss with you. Yes, Ross can speak with experience. Your inquiries are invited.

American-Standard, Ross Heat Exchanger Division, Buffalo 5, N. Y.
In Canada: American-Standard Products (Canada) Limited, Station D, Toronto, Ont.

* American-Standard and Standard ® are trademarks of American Radiator & Standard Sanitary Corporation.

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ROSS HEAT EXCHANGER DIVISION

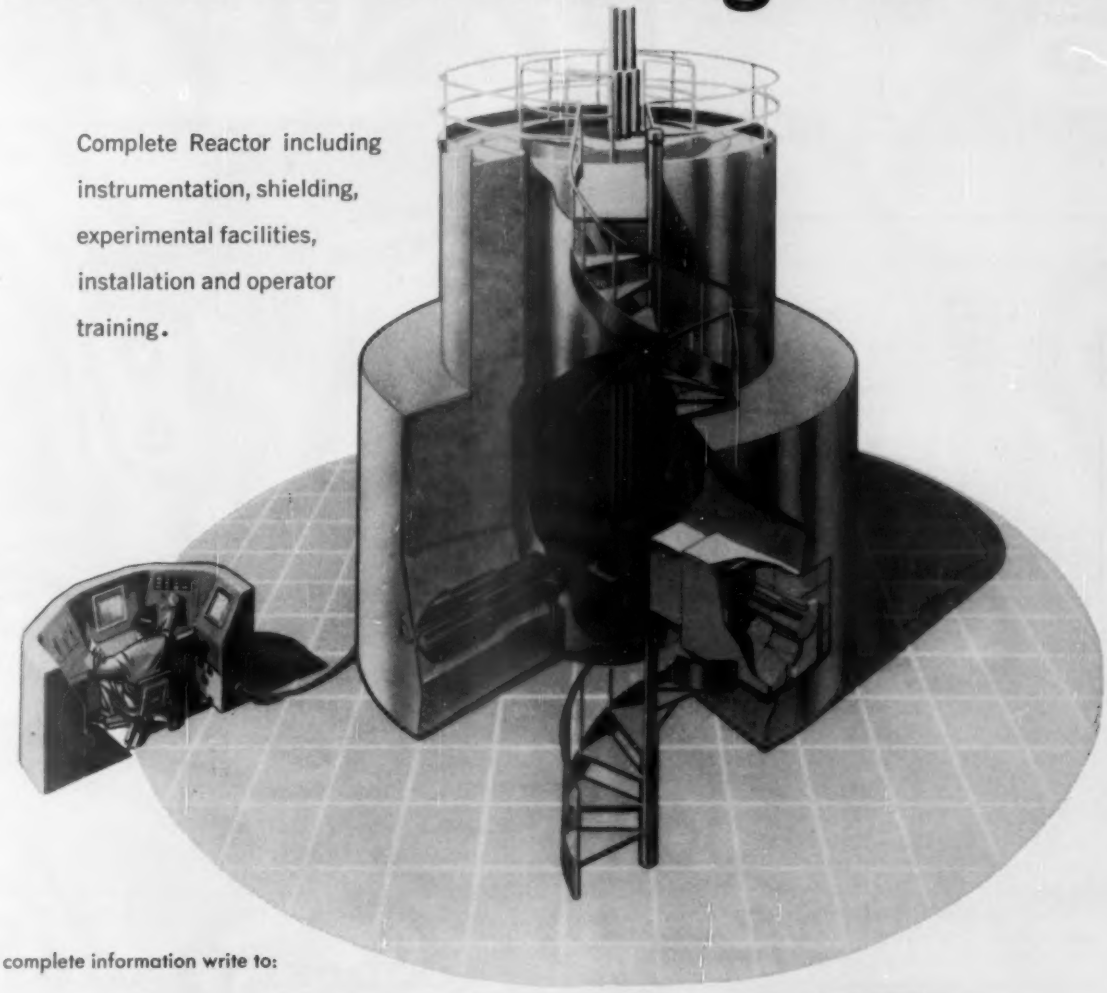
acf Announces

10 KW POOL TYPE

MODEL #605

research & training reactor

Complete Reactor including instrumentation, shielding, experimental facilities, installation and operator training.



For complete information write to:

NUCLEAR PRODUCTS ERCO

Division of ACF Industries Incorporated

508 Kennedy Street N.W., Washington 11, D.C.

acf

CAST nuclear stainless steel valves and fittings now proved economical with superior strength

Cooper Alloy cast nuclear-service stainless steel valves and fittings are saving money, providing greater strength in AEC-contract plants today. Here's the story:

This Cooper Alloy stainless steel fitting for nuclear service, here being machined, possesses a yield strength of 26,000 psi at 650°F.—20% higher than values specified by code.

Cooper Alloy 16″ stainless steel gate valve body illustrates the wide range of nuclear valves and fittings now being cast by Cooper Alloy for atomic energy service.

YIELD STRENGTHS: CAST vs. FORGED STAINLESS STEEL

Cast Stainless Steel
SA351-CF8 . . . . . 18,400 psi @ 650°F.(1)

Forged Stainless Steel
SA182-F8-304 . . . . . 17,900 psi @ 650°F.(1)

Cooper Alloy Cast Stainless Steel
ASTM351-CF8 . . . . . 22-27,000 psi @ 650°F.(2)

(1) Figures represent minimum yield strengths required by ASME Unfired Pressure Vessel Code, Section VIII, and have been calculated as follows:

$$YS = \frac{\text{allowable stress}}{62.5\%}$$

(2) Figures taken from tests of actual heats of material manufactured by Cooper Alloy for the AEC's SPERT III program at Idaho Falls, Idaho (see Nucleonics, Aug. '57).

Strength: As the figures in the accompanying chart show, Cooper Alloy is currently achieving what many have described as "the impossible": producing 304 ELC stainless cast valves and fittings consistently with yield strengths of 22-27,000 psi at 650°F.! These superior physical properties are finding wide application in meeting the exacting strength and economy demands of the nuclear industry.

How It's Done: These outstanding properties have been achieved by utilizing skills developed through Cooper Alloy's over 35 years of experience in casting stainless steel exclusively. In particular: • Use of proper directional solidification, achieved by proper mold design, plus foundry know-how in metal feeding, ensures a sound solid casting. • An exact balance of chemical composition develops the maximum strength characteristics inherent in the complex structure of stainless steel alloys. • Incorporation of foundry considerations into valve and fitting designs ensures maximization of the alloy's and the item's potential.

Quality Controls: In addition to all usual checks, such as 100% X-ray examination and dye-penetrant surface testing, all components are subjected to a 6,000 psi hydrostatic pressure test.

The Costs: Savings up to 40% have been achieved with sizes of fittings running from 8″—24″.

Want more information? Telephone or write the Nuclear Division, Cooper Alloy Corporation, Hillside, N. J.

COOPER ALLOY
Corporation • Hillside, New Jersey
THIRTY-FIVE YEARS OF STAINLESS STEEL PIONEERING

and it costs no more!

Now, with the many accessories offered, the Central Research Manipulator lets you perform an even greater variety of intricate operations. All of these accessories are remotely interchangeable . . . each is the product of precision craftsmanship and exacting control of tolerances. The manipulator itself has that inherent "sense of feel" which is the result of continuous design improvement and rigid quality control throughout every phase of manufacture. Field maintenance is simplified by standardization and interchangeability of parts, yet each manipulator is "custom built" by skilled craftsmen with years of experience. Because of this individual attention the CRL Manipulator is easily adapted to your particular needs.

If you use—or plan to use—hazardous materials that require intricate handling, CRL Manipulators will speed up your production or research program. We will also be glad to advise you on the layout of hot cells and other research areas, to help you gain maximum benefit from your CRL Manipulator.

central research manipulators
from basic Argonne National Laboratory design

write today for complete information to:

Central Research
laboratories, inc.
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Dept. 101

Father and son total 70 years machining steel

At the U. S. Steel Homestead Forge Shop, you find a lot of men who carry on in the shoes of their fathers. Gus Seitz's father was a Journeyman Machinist for 30 years before he retired. Gus started in the shop when he was 16, worked as an apprentice, Journeyman Machinist, Inspector. After six years in Production Control, he moved up to General Foreman, a post he has held for 10 years. With 40 years of machining experience behind him, Gus supervises a staff of 256.

His most important job: see that the work is carried out to the customer's specifications, *on time.*

The forgings in the picture illustrate some of the scheduling problems that Gus has to solve. These are closure head flanges for a nuclear reactor—130″ OD, 88″ ID and 35″ high. Ingots were cogged, upset, punched and forged over a mandrel. Then they received the preliminary machining. Next came a quench-and-temper heat treatment to meet the physical properties needed by the reactor builder. Then followed about 10 days of testing for microstructure, tensile strength and ductility. Finally, the forgings were scheduled back onto the 20-foot vertical boring mill for final machining.

With men like Gus Seitz riding herd on your USS Quality Forging order, you can rest assured that money won't buy a better piece of steel. U. S. Steel has the men, the know-how, the equipment and steel to turn out forgings for the most critical service, and we're eager to help you solve your forgings problems. Write for our free 32-page booklet on USS Quality Forgings. Send your requests to United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pa. *USS is a registered trademark*

USS

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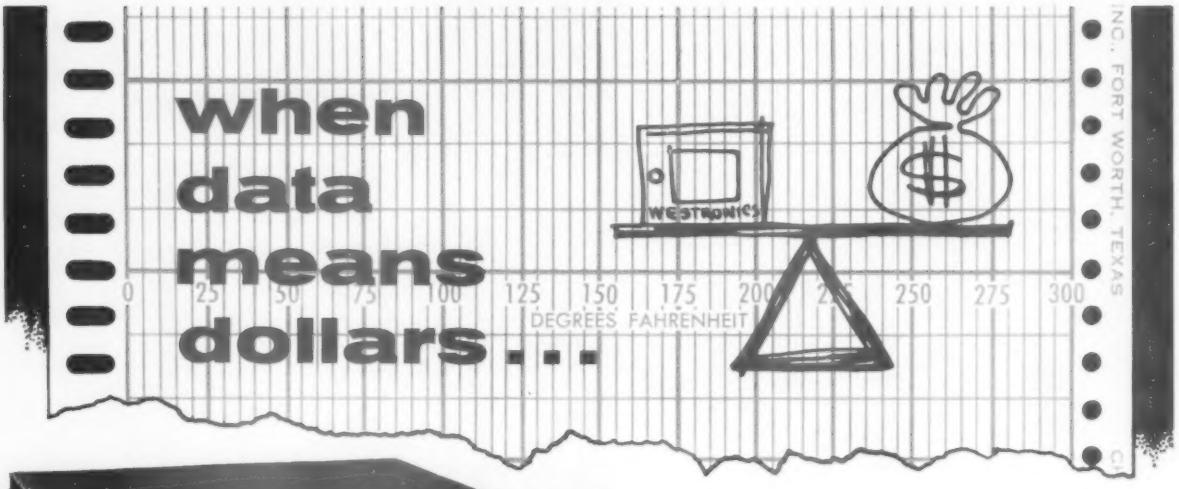
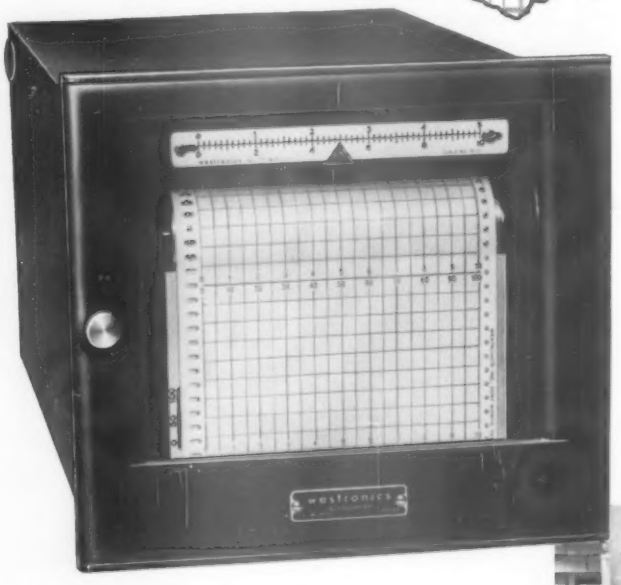
when data means dollars . . .





Be sure that your data is accurate. Westronics' rugged Single Pen* Miniature Recording Potentiometer is better than 0.5% accurate, with a one second full scale pen travel.

This compact recorder, fits in 9¾" x 8½" panel space, has more optional features than any other small recorder built today. The front and back set limit switches, plug-in range units, and transmitting slidewire are among the optional features of the Westronics Single Pen Miniature Recording Potentiometer which adapt this recorder to a variety of uses. The recorder is widely used by many industrial plants and missile testing operations.

PRICED ONLY

$490.00

IMMEDIATE DELIVERY

Send for literature

*Miniature Dual Pen Recorders of same dimensions also available.

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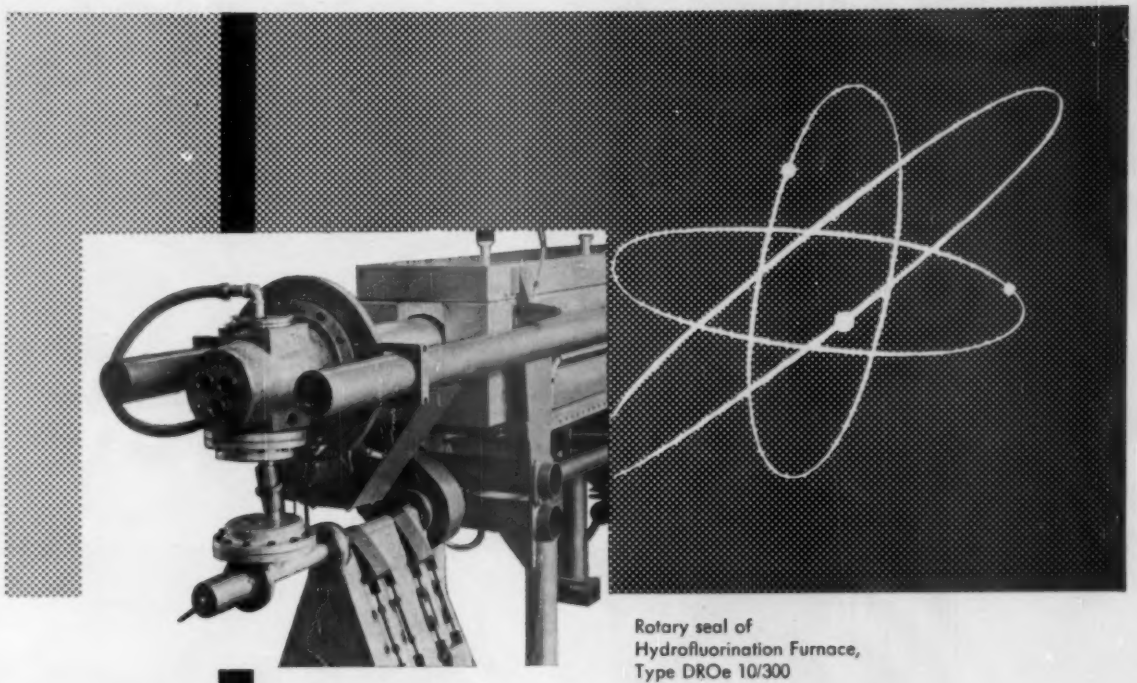

Rotary seal of
Hydrofluorination Furnace,
Type DROe 10/300

Uranium Tetrafluoride

can be produced in rotary tubular furnaces without contamination with neutron parasites. To find out what materials can be used and how rotary seals for hot hydrofluoric acid must be designed, years of chemical, metallurgical and engineering experience had to be combined.

Our production program includes:

1. reactor grade metals like uranium, thorium, zirconium and others,
2. metallic and ceramic nuclear fuel elements for heterogeneous reactors,
3. equipment for the production and fabrication of reactor materials.

DEGUSSA

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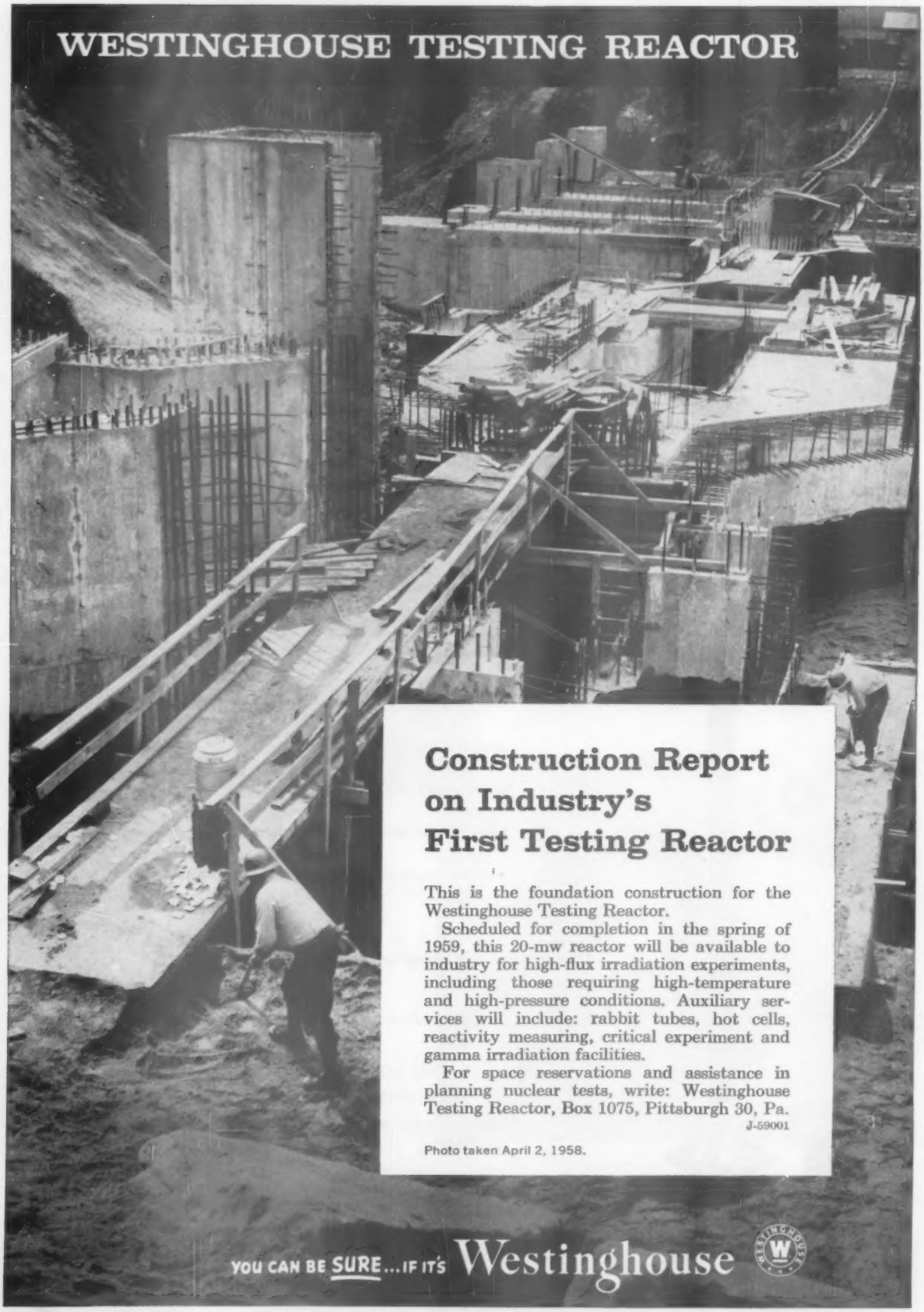


Construction Report on Industry's First Testing Reactor

This is the foundation construction for the Westinghouse Testing Reactor.

Scheduled for completion in the spring of 1959, this 20-mw reactor will be available to industry for high-flux irradiation experiments, including those requiring high-temperature and high-pressure conditions. Auxiliary services will include: rabbit tubes, hot cells, reactivity measuring, critical experiment and gamma irradiation facilities.

For space reservations and assistance in planning nuclear tests, write: Westinghouse Testing Reactor, Box 1075, Pittsburgh 30, Pa.

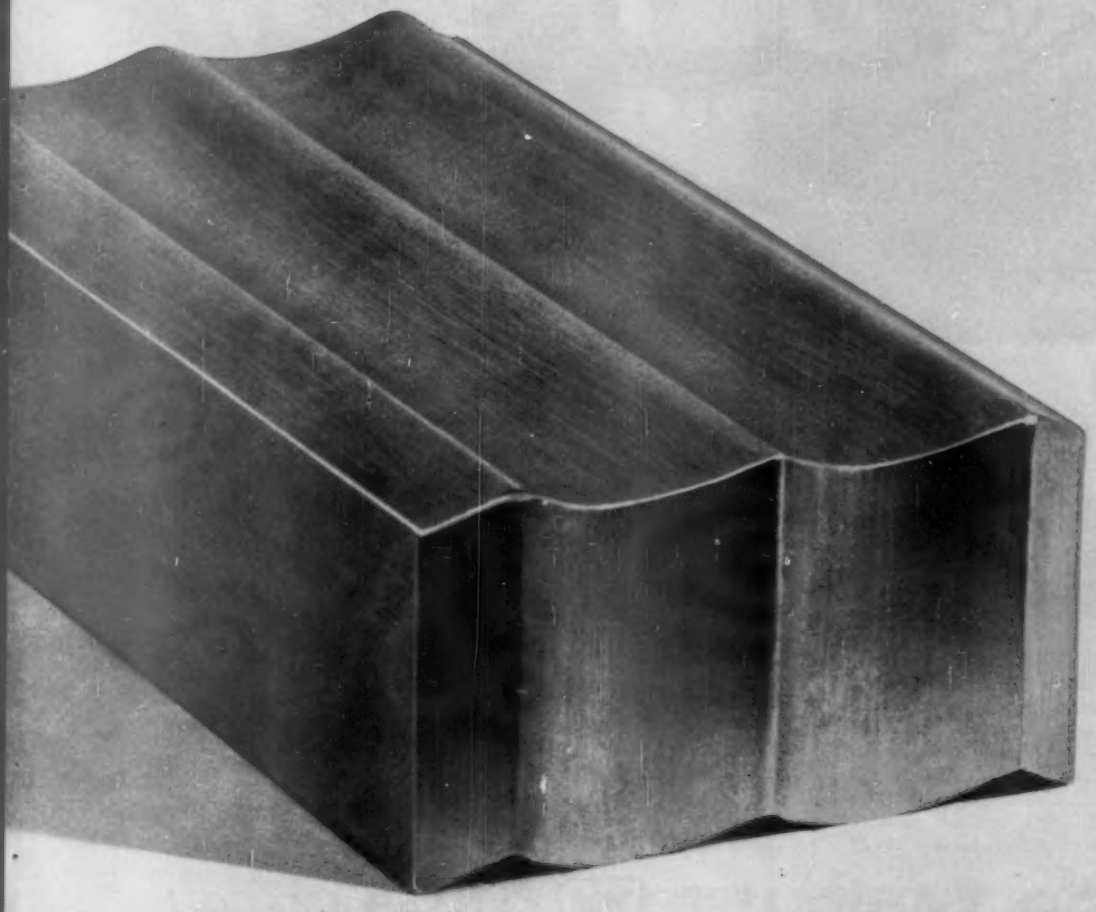
J-59001

Photo taken April 2, 1958.

YOU CAN BE SURE...IF IT'S Westinghouse

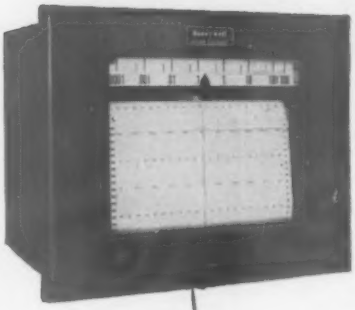
Interlocking lead brick and other unique lead protective products have been designed by Federated for the nuclear industry. Convenient lead containers, one pound to 10 ton casks, and larger to your precise specifications. Federated is long experienced in fabrication of cast, rolled and extruded lead products, sheet, plates, and piping. Asarco's Central Research Laboratory offers a wealth of information about temporary and permanent structures to house or transport radioactive materials. For lead protection call one of the convenient offices of Federated Metals Division of American Smelting and Refining Company, 120 Broadway, New York 5, N. Y. In Canada, Federated Metals Canada, Ltd., Toronto and Montreal.

FEDERATED METALS DIVISION OF



ASARCO

AMERICAN SMELTING AND REFINING COMPANY



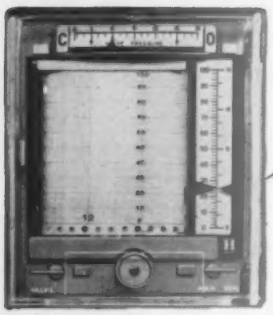
ElectroniK recorders . . . with special scales for nuclear process variables.

MegopaK thermocouple wire . . . designed for fuel element temperatures in nuclear installations.

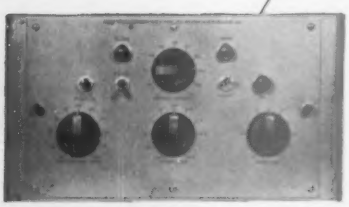
Safety amplifiers . . . one of eight special units for reactor control.

from ONE source

Pressure gages . . . for coolant flow, monitoring, and other applications.



Tel-O-Set miniature instruments . . . for use on graphic panels or to save space.



Three-mode controllers . . . matched to reactor characteristics.

. . . reactor instrumentation for every need

What are your instrumentation requirements—a single instrument . . . a packaged nuclear reactor control system? You can place undivided responsibility with Honeywell for everything from initial specifications to complete installation and startup.

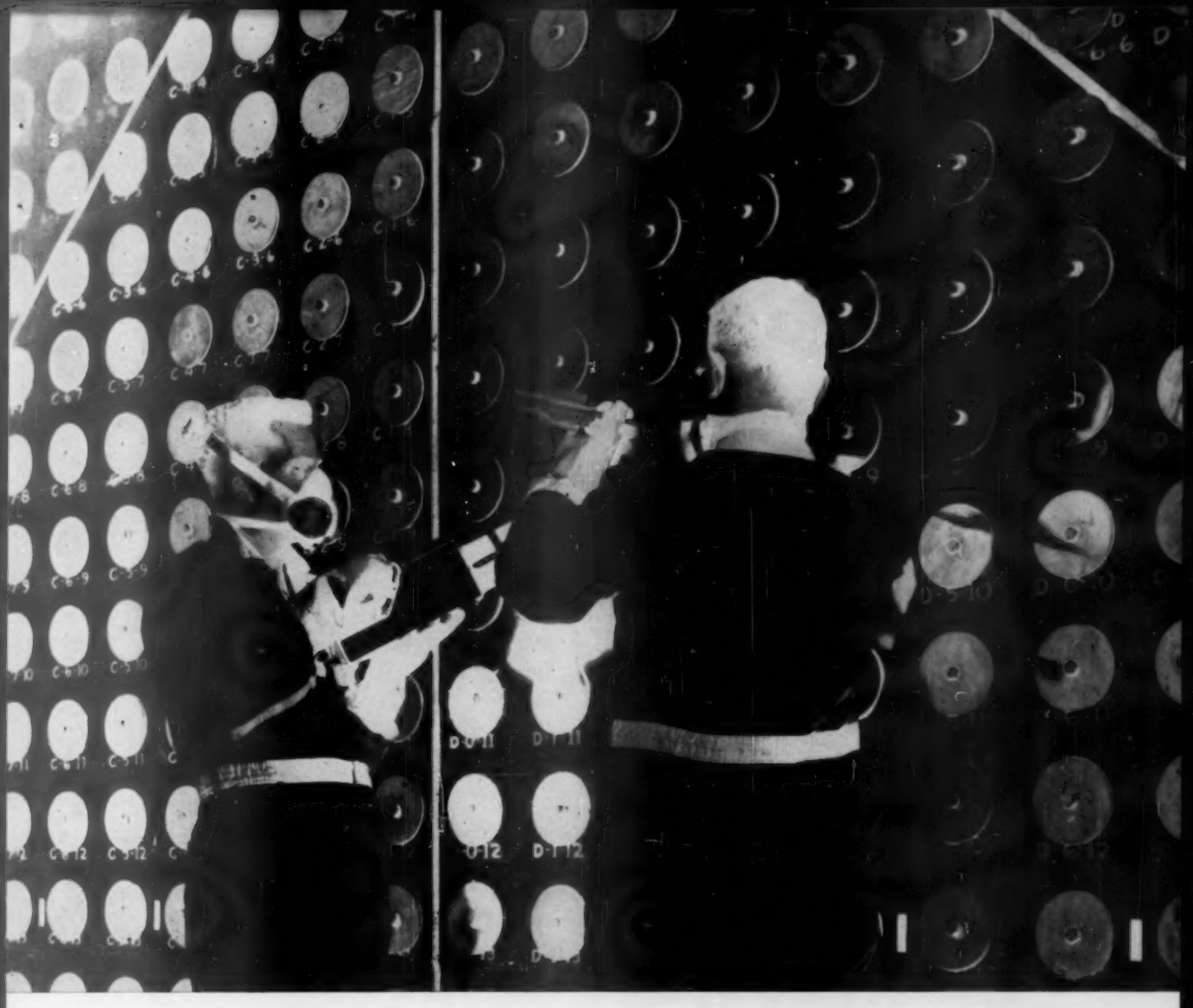
From this one source, the world's largest instrument manufacturer, you also receive expert engineering assistance in application and maintenance . . . and prompt, efficient service from a branch office near you.

Your local Honeywell sales engineer will be glad to help you select the reactor instrumentation you need. Call him today . . . he's as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Pa.

Honeywell

First in Controls



Fuel-element irradiation studies at 1700°F

Irradiation studies of experimental fuel elements at high temperatures (1700°F) for a projected gas-cooled reactor design are now being carried out by Ford Instrument Co. engineers at the reactor facilities of Brookhaven National Laboratory.

Major aims of the fuel-element irradiation programs are to study fission product diffusion and leakage, and to secure radiation damage information. The studies are directed toward development of a fuel element that can be fabricated economically with a low reject rate, that uses material of low enrichment, that can be reprocessed economically and be economical of fuel inventory.

Irradiation of fuel elements at high temperature is just one of the nuclear studies and projects completed or now under way by Ford Instrument. Others include: design of a complete closed-cycle gas-cooled reactor, manufacture of control rod drive mechanisms (e.g., as used in the submarine, *Seawolf*), control rod position indicators, magnetic and transistor amplifiers for nuclear applications, and studies of control rod and reactor materials. In addition, Ford Instrument is conducting numerous feasibility and experimental studies in the nuclear field, including the application of digital techniques to reactor control.

To find out how you can put Ford Instrument nucleonic capabilities to work on your problems, write to Nuclear Sales, Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.

8.15

FORD INSTRUMENT CO.

DIVISION OF SPERRY RAND CORPORATION

A CREATIVE TEAM OF SCIENTIFIC, ENGINEERING AND PRODUCTION TALENT

NOW... A COMPLETE NUCLEAR "PACKAGE FUEL" PLAN

Another SYLCOR first! All the customer needs is the allocation for the nuclear material required in the fuel. For a single price, SYLCOR will do everything else, straight through to the delivery of the completed nuclear fuel elements.

SYLCOR's pioneering nuclear "package fuel" plan means substantial savings in both time and money to the users of nuclear fuels.

Here's how SYLCOR's plan works:

- SYLCOR will quote one fixed price which will be the *total and only* charge to the customer for the delivery of the completed elements for core loading.
- The customer need only obtain an allocation for the special nuclear material specifically required in the fuel. It will no longer be necessary for him to get extra allocation to cover scrap and losses in the production of standard enrichment fuels.
- SYLCOR will arrange and pay for the conversion of UF_6.
- Where rapid delivery is important, SYLCOR will supply from its inventory all special nuclear material required, replacing this material from the customer's allocation before delivery of fuel.
- SYLCOR will assume responsibility for processing losses and scrap reprocessing of special nuclear material.
- SYLCOR will pay all use charges during the entire fuel element production period, with the customer assuming the direct use charge on only the special nuclear material in his fuel element and only *after delivery* of the completed fuel elements.

The extreme simplification of this SYLCOR-developed "fuel package" plan permits SYLCOR to serve you better by providing the finest quality nuclear fuel quickly and economically. *For full details on this new complete nuclear fuel plan, write to our Marketing Staff at Sylvania-Corning Nuclear Corporation, Bayside, N. Y.*

SYLCOR

SYLVANIA–CORNING NUCLEAR CORP

Cylinder for ALCO *nuclear pressurizer is overlay-welded with stainless steel. Pressure vessel meets stringent Navy specifications for nuclear components.*

THE NEW DEFENSE AGAINST CORROSION

Pressure vessels in nuclear plants operate under highly corrosive conditions. Solid stainless-steel construction resists this corrosion, but the cost is very high. Now ALCO has developed a welding technique that clads the inside of non-stainless nuclear vessels with stainless steel—providing the same resistance to corrosion, but at less cost.

This new development is being used on ALCO-built pressure vessels for various nuclear programs. The stainless steel is welded to the interior of a high-strength cylinder forged by ALCO. After the stainless surface is machined, a seam-free, corrosion-resistant vessel results.

In this particular product, ALCO has complete control of quality—from steel-making through forging, overlay-welding and final fabrication. Unique experience and facilities like this have made ALCO a leader in building components for almost every nuclear project to date.

Information on ALCO nuclear and thermal equipment is available at your nearest ALCO sales office, or write ALCO Products, Inc., Department 136, Schenectady, New York.

ALCO

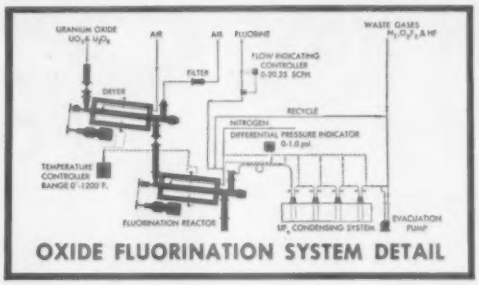
ALCO PRODUCTS, INC.

NEW YORK

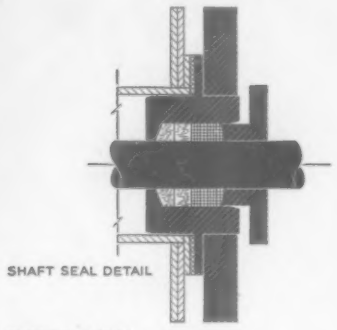
SALES OFFICES IN PRINCIPAL CITIES

Locomotives · Diesel Engines · Nuclear Reactors · Heat Exchangers · Springs · Steel Pipe · Forgings · Weldments · Oil-Field Equipment

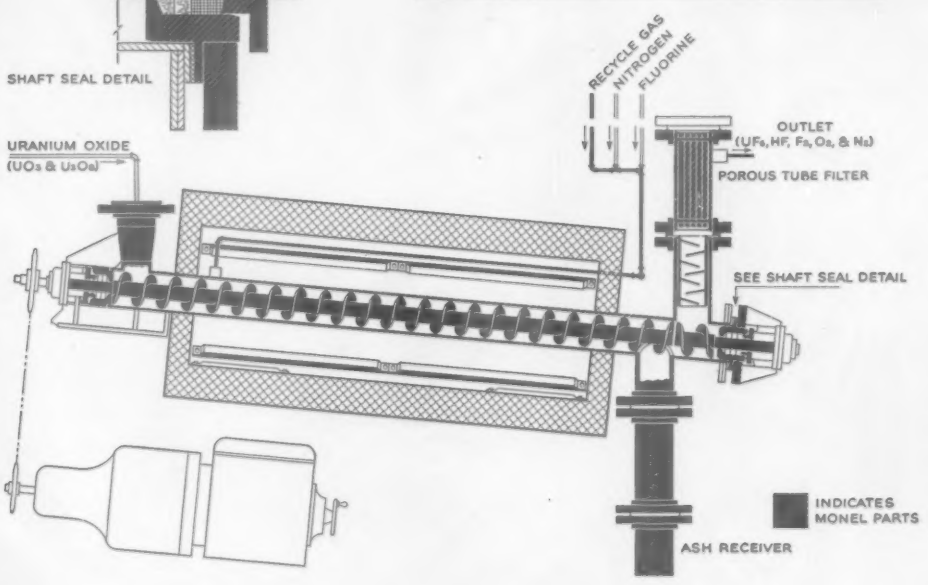
Information courtesy of Union Carbide Nuclear Company.



OXIDE FLUORINATION SYSTEM DETAIL



SHAFT SEAL DETAIL



DRYER AND FLUORINATOR DETAIL

Corrosive conditions — To get an idea of the corrosive conditions faced by Monel alloy in this unit, look first at the small schematic. A dryer (same design as the fluorinator but made of nickel-containing stainless steel) feeds dry UO_3 and UO_4 to the fluorinator. The Monel screw carries the oxides into the hot zone. Here it is reacted at 1050°F with 98% fluorine. Outgoing gases (UF_6, F_2, O_2, N_2 and trace HF) are filtered and passed through Monel piping to condensers where refrigeration separates UF_6.

In Oak Ridge fluorinator...

Mechanical versatility of Monel proves as useful as its corrosion resistance

Monel* nickel-copper alloy is a "doer"!

And that goes for *mechanical design* as well as corrosion prevention. Take the fluorinator shown above, used in the uranium recovery unit at Oak Ridge. In the unit, uranium oxides are reacted with hot fluorine to form uranium hexafluoride. Wherever hot fluorine contacts metal, Monel alloy is used.

From the viewpoint of corrosion resistance this application of Monel alloy is not surprising. Monel alloy stands out in its resistance to corrosion by fluorine and its compounds. Hot or cold. Liquid or gaseous.

From the viewpoint of mechanical design, the versatility shown by this useful alloy is illuminating. Monel is used: (1) in Schedule-40 seamless pipe form; (2) as a welded fabrication (the screw); (3) for shafting; (4) in machined castings; (5) for piping. (See diagram above)

Monel alloy meets the diverse physical, mechanical, and thermal requirements of all these uses. Furthermore, it is produced in all mill forms.

If you have a hot fluorine corrosion condition that calls for action, Monel alloy may be your metal. For further information, write for our new 24-page booklet "Handling Fluorine and Fluorine Compounds With Inco Nickel Alloys".

*Registered trademark

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street — INCO — New York 5, N. Y.

INCO NICKEL ALLOYS

NUCLEONICS
ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION

JUNE, 1958

Euratom–U. S.: A Vital Tie

ALTHOUGH much has been accomplished on the development of reactor systems in the U. S., there has recently been a push to develop technology more particularly suitable for foreign consumption. Pressure for this has come, of course, from the growing interest abroad in the acquisition of nuclear facilities. And this has resulted in sharp competition between the U. S. and the U. K. for this market.

Perhaps best exemplifying the foreign interest in reactors—and also the "battleground" for American and British industry—is the Euratom area, the six-nation Western European group. In 1957, Euratom announced a dramatic "target" of building 15-million kilowatts of nuclear power plant capacity by 1967. This was a target that most considered unrealizable but worthy of establishment as a goal to spur the member nations.

With Euratom only having come into formal existence at the start of this year, it was uncertain how long a wait there would be before the group took its first real step. It is now encouraging to learn that a giant step has just been taken, a step that may well have profound implications for industry in both Europe and the U. S. There is reported elsewhere in this issue (p. 18) that the Euratom-U. S. negotiating team has reached agreement on a program of U. S. support for a 1-million-kw "starter" program.

PROVISION that apparently has been made for the sale of enriched uranium to Euratom will go a long way towards encouraging Euratom interest in enriched reactor systems, and consequently in fostering interest in the acquisition of U. S. enriched designs.

Apart from this political development, there are two other indications of strengthening support for enriched systems. One is that the British, the strongest advocates of natural uranium, are planning to use slightly-enriched fuel in their advanced reactor designs.

The other portent for the future is the similarity in conclusions drawn by the several U. S. groups that have just finished studies of gas-cooled technology and economics. The most interesting conclusion is the strong support for enriched fuels over natural. There is recognition in the U. S., however, of the existence of some opposition abroad to being tied to U. S. enriched uranium. Thus, it has been suggested that although first cores of gas-cooled plants might be U^{235}, a natural-uranium–plutonium cycle might be used later on with the Pu providing the enrichment.

WHICHEVER route is followed in Euratom reactor building—if in fact it be any *one* route—it is important that Euratom is at last getting under way. There is much to be learned about power reactor building—very much. And it is encouraging that the U. S. is stepping forth with boldness to offer Euratom very extensive assistance. "Success (of Euratom) could mean millions of dollars in equipment and services to be supplied by American industry," AEC Commissioner John F. Floberg told a NUCLEONICS seminar last month. "We are giving it top priority in Washington," he said.

Jerome D. Luntz Editor

Scintillation Counting—1958

Scintillation counting seems to have reached a certain maturity, and consolidation of previous advances is the order of the day. Nevertheless interesting new ideas abound, a review of the status of scintillation counting reveals. For example new progress has been made on the incorporation of heavy elements into plastic scintillators (p. 55) and organic phosphors are revealing hidden capacity for neutron detection (p. 54). Of circuit ingenuity there seems to be no end, one of the more striking developments being the vernier chronotron (p. 57). Photomultipliers for the micromicrosecond range are on the drafting boards (p. 58). Perhaps the most promising single proposal is the use of arrays of scintillating rods to reveal the tracks of high energy particles (reported in full on p. 60). NUCLEONICS here presents its biennial review of the state of scintillating art based on the Sixth Scintillation Counter Symposium, held in Washington recently. Complete proceedings will be published this fall in volume 5, No. 3 of the *Transactions of the Professional Group on Nuclear Science of the IRE.*

SCINTILLATION COUNTING —1958

What's New in Scintillators? . . .

. . . Neutron Detection Via Slow Phosphor Decay

The recent observation that certain organic phosphors have a slow (200–400 mμsec) component of decay whose intensity depends on the nature of the exciting particle points the way to neutron detection with very low gamma-ray background. A fast-neutron detector having an efficiency of 20–50% and a gamma-ray efficiency of less than 0.1% seems feasible. Roughly speaking the long-lived components contain about 10% of the total light output and the intensity is doubled for recoil-proton excitation as compared with electron excitation.

The fast components (typically a few mμsec; 6.2 mμsec in the case of stilbene) are found to be independent of the nature of the exciting particle. Thus it is not essential to employ a fast photomultiplier to be able to distinguish. In fact, discrimination might be improved further by adjusting interdynode voltages so that the phototube will saturate on the high peak currents in the early stages of the pulse, thus enhancing the differences in the slow components.

To distinguish between the two a cathode-ray-tube display has been used in which the peak pulse height provides the Y deflection and the total charge in the photomultiplier pulse provides the X deflection for the CRT spot. Since neutron-induced scintillations have effectively a longer decay time than those induced by gammas, these spots lie along two distinct loci corresponding to the two types of particles (see figure).

Many organic phosphors, solids and liquids both, show these properties; stilbene, anthracene, quaterphenyl, toluene, and a xylene-naphthalene-methyl borate solution are among them.

Cathode-ray-tube display shows different loci for neutron and gamma-ray pulses from plastic scintillator

Based on a paper by R. B. Owen, AERE, Harwell, England.

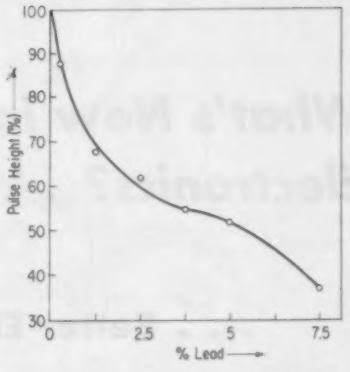
. . . Plastic Scintillators Loaded with Heavy Elements

Plastic scintillators containing 7% lead and having 50% of the pulse height of the metal-free plastic have been successfully fabricated, by placing a lead octoate-methacrylate mixed salt in a vinyl toluene base plastic. (Organic acid salts of the heavy elements are poorly associated and hence soluble in organic solvents.) This high point is not very reproducible and more certain results can be obtained with a lead trimethylacetate-methacrylate mixed salt in the same base plastic (see figure for typical pulse-height vs lead-content characteristic.) In both cases the primary fluor is 0.5% PBD; 0.1% POPOP is the secondary fluor. Because of the high photoelectric cross section of lead the sensitivity for low-energy-gamma-ray detection is typically five times greater than with the standard plastic scintillator for small counters and low discriminator settings.

Present efforts are directed towards making heavy-element-loaded plastic scintillators in "large" (6-in.) sizes and refining present techniques to permit the inclusion of 10–20% of the heavy elements without serious light loss.

Gadolinium and samarium have also been incorporated in plastic scintillators by this route and offer some promise as thermal-neutron detectors.

Based on a paper by Mark Hyman, Jr. and James J. Ryan, Pilot Chemicals, Inc., Watertown, Mass.



Pulse height as a function of lead content for lead-loaded scintillator

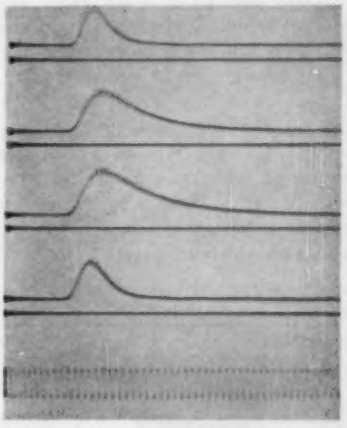
. . . Decay Times of Scintillators Pinned Down

Cathode rays have been used to bombard organic scintillators in a new study of their very short decay times. A coaxially mounted mercury switch initiates the chain of events by sending pulses through appropriate delay cables to two sweep generators. One sweep generator operates the gun of an electron accelerator, the other operates the data-displaying oscilloscope. The electron beam in the accelerator is gated and deflected across a slit to produce a short pulse. The gun itself is a commercial 5XP oscilloscope gun, sealed onto the continuously pumped vacuum system. Peak beam current is about 10 μa. The usual system of postdeflection acceleration is used and the electrons arrive at the slit with an energy of 24 kev. After emerging from the slit, the electrons are further accelerated to a total energy of 75 kev. They are magnetically focussed on the exit window, a nickel foil about 1.7 μ thick. The anode and exit window are at laboratory ground potential. The scintillator is placed directly outside the exit window, where it is bombarded by the transmitted beam. The orientation of the accelerator tube facilitates the bombardment of the free surface of a liquid scintillator. Beneath the scintillator is a 1P28 phototube whose output is fed to a travelling-wave oscilloscope.

Because of the uniformity of pulse amplitudes, the use of time exposures is permissible in photographing the pulses. This serves to average the statistical fluctuations to a certain degree. The pulses are recorded on glass photographic plates. A typical plate is shown in the figure.

For most applications, the sweep speed of the accelerator is adjusted so that the beam is over the slit for approximately 2×10^{-10} sec. This provides a burst of about 10^4 electrons. Based on the accelerating potential of 75 kev, this results in a total energy of 750 Mev per pulse. (This value has been confirmed by direct comparison with the pulse height of the internal-conversion electrons from Cs^{137}.) It is important to note that although the pulse is large, the penetration is small. This fact is of great importance in experiments where self-absorption of the fluorescent radiation must be avoided. On the other hand, the concentration of energy in the sample is not so great that interactions between the individual scintillations occur. From the value of 0.5 mm for the cross-sectional diameter of the beam, one can calculate that in a typical scintillator the average proportion of molecules affected by a pulse is only about one in 10^5.

Results. Among the first experiments to be carried out with this apparatus was an investigation of the dependence of the decay time upon activator concentration in liquid scintillators. Results of these experiments have a direct bearing on our understanding of the process of energy transfer from solvent to activator in these materials. The data on decay times not only supplement the data on light output vs concentration, but in many instances are more revealing and more easily interpreted. In particular, the measurements of decay time have already disclosed an important difference between the processes of energy transfer in liquids and plastics—liquid scintillators follow the theory developed by Kallmann and Furst, but solids do not.



Scintillator decay as observed with travelling-wave oscilloscope. Timing-wave frequency is 1,000 Mc

Based on a paper by R. K. Swank, et. al., Argonne National Laboratory, Lemont, Ill.

What's New in Electronics? . . .

. . . Better Electronics for Neutron-Gamma Analysis

Highly stable electronics make possible what may be the first process line neutron-gaging method (see NU, April '58, p. 115). It was described by W. B. Nelligan and J. Tittman of Schlumberger Well Surveying Corp., Ridgefield, Conn. The system detects prompt gamma photons arising from thermal-neutron capture in N^{15}.

Figure at left below shows the system as it is designed. Fast neutrons from a 5-c PoBe source are moderated by the hydrogen present in organic material. Captures in N^{15} produce 10.8-Mev prompt gammas which are detected in four NaI crystals. Pulses from photomultiplier tubes go through a discriminator set to eliminate most of the low-energy spectrum. Then they are stretched, analyzed, and recorded. Bismuth shields reduce the number of neutrons striking the crystals directly. Paraffin around the crystals reduce this number further, and a constant-temperature water bath decreases detector instability caused by temperature changes.

Problems

The situation is not a simple one. For required precision each crystal must recognize 10 nitrogen counts per sec in the presence of a background of 10^5 cps in the low-energy spectrum. Graph shows the spectrum presented to the crystals.

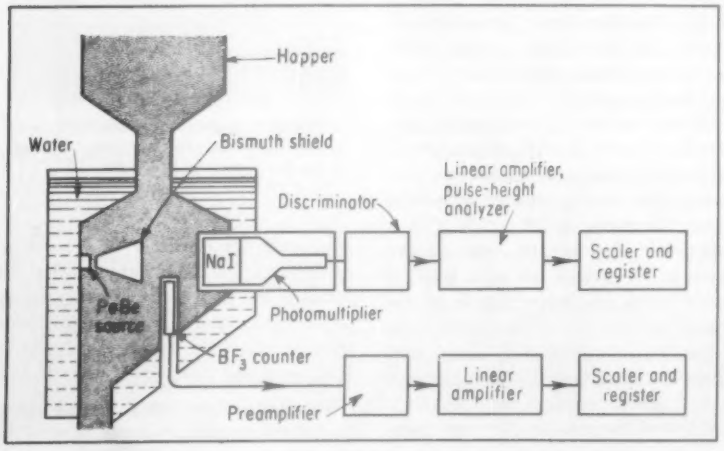
Stability must be exceptionally good because of the steep slope of the background counting rate at the energy of the nitrogen photons. Combined gain drifts of crystal, photomultiplier, and electronic circuits must be $<0.75\%$ between calibrations at 4-hr intervals.

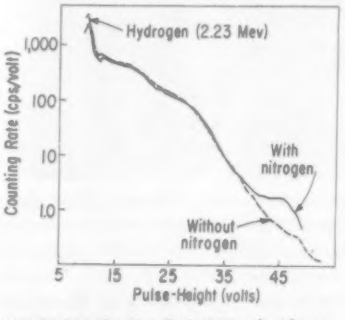
Solutions

Each detector head has a 3×3-in. NaI(Tl) crystal and a Du Mont 6363 photomultiplier operating at 1,300 volts. Outputs are fed into a highly damped resonant circuit made up of a $2\mu h$ inductance, distributed circuit capacitance, and a silicon diode. This produces 40-mμsec, 200-millivolt pulses in response to 10-Mev photons.

Stability of a Hamner amplifier–pulse-height-analyzer combination was increased by increasing feedback and substituting premium circuit components at critical locations. Tests with a mercury pulser showed a final over-all stability of $\pm 0.2\%$ per day. Temperature regulation is required.

Addition of crystal and photomultiplier introduced more drift than existed in all of the rest of the system. At room temperature the temperature coefficient of gain was $-1\%/°$ C. Drift has been reduced as much as possible by providing a 3-in. water jacket in which temperature is held constant within $\pm 0.1°$ C. Maintenance of constant temperature is made easier by 4–9 in. of paraffin, around the detector heads, provided mainly as a neutron shield.



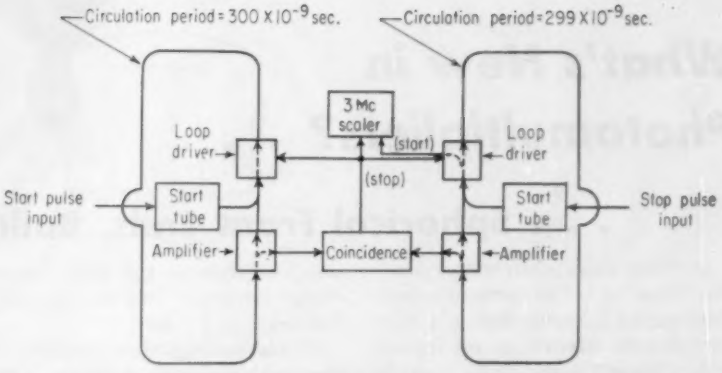


NEUTRON-GAGING SYSTEM (left) recognizes prompt N^{15} gammas in spectrum (above) to measure protein density in organic materials. Steep slope of background in region of interest dictates highly stable circuits

. . . Vernier Chronotron Simplifies Pulse Timing

Time-of-flight measurements are frequently limited by the resolution of the timing system. The chronotron, developed to improve this resolution, is an instrument that measures a time interval by establishing the spatial positions of two pulses in a transmission line or a pair of them (*1–3*). The figure (right) shows an instrument that departs from these designs to provide solutions for the two major recurring disadvantages.

The system causes the two pulses to race around two similar loops with slightly different delay times (*4, 5*). When the later pulse, travelling around the circuit with the shorter delay, catches up with its predecessor, coincidence at the output stops the sequence and causes a count to register in the proper channel of an analyzer.



KEY TO OPERATION of vernier chronotron is slight difference in circulation time in delay-line loops. Pulse in loop at right gains 1 mμsec on pulse in loop at left every time it makes a complete transit. Number of transits required to catch up gives interval between arrival of pulses **FIG. 1**

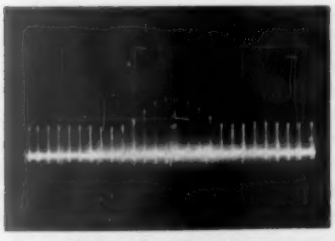
Design

The vernier chronotron overcomes the following disadvantages of the usual chronotron: (1) the requirement of separate fast coincidence circuits for each of two circuits and (2) limitation of the number of usable channels by pulse distortions at points where transmission lines are tapped. By making each delay circuit into a loop and feeding both loops into the same coincidence circuit both difficulties are eliminated.

Figure 1 shows the basic design. An initial pulse is fed into the left-hand loop through the "start" tube. The pulse circulates through the coaxial cable and the two-stage regenerative amplifier formed by the driver and the amplifier. At the same time gating circuits make the loop at the right sensitive to a follower pulse. When it arrives it is fed into the right-hand loop.

With the indicated circulating periods the follower pulse overtakes the initiating pulse at the rate of 1 mμsec per transit. The pulses circulate until the coincidence circuit fires and stops them. A binary count of the number of transits preceding coincidence indicates the time interval between insertions of the two pulses—and, as a bonus, provides the address for recording the pulse.

Figure 2 shows the oscilloscope pattern at the coincidence-circuit input as one pulse catches the other and passes it. (To make this pattern an external kill signal was substituted for the usual one so that circulation continued after coincidence.) Each of the small pulses is really double—one pulse from each loop. As they come into coincidence the pulse height becomes greater, and a discriminator is biased to pass only the coincidence-augmented pulses. Pulse shapes are controlled by shorted lines on the input grids of the amplifier stages and operation of the tubes to saturation.



COINCIDENCE INPUT as shown by oscilloscope. Peak of envelope marks moment when follower pulse overtakes initial one **FIG. 2**

Gating

Fast gates prevent circulation of single pulses and the entry of a second pulse pair before a previous analysis is complete. Gating is controlled by the screen grids in the tubes of the circulating loops. All of these tubes are secondary-emission pentodes, the circulating pulses being passed on by their dynode stages.

Gating sequence is as follows: An initial pulse comes in, gates *on* the loop driver tube in the follower-pulse loop, gates *off* the start tube in its own loop and proceeds through its coaxial cable. If no follower pulse arrives, the initial pulse stops at the *normally off* amplifier stage. If a follower pulse does arrive, the loop driver in the follower-pulse loop gates *on* the amplifier in the initial-pulse loop and gates *off* the start tube through which it entered. Both pulses then circulate to coincidence. Thus the gating makes it impossible for a pulse to circulate in either loop without a pulse in the other.

It takes 30 mμsec to open each gate. Thus, since the circulation time is 300 mμsec, the interval to be measured must be >30 mμsec and <270 mμsec.

Stability of the system depends primarily on transconductance of the tubes, signal-transit time in the tubes, and properties of the cables.

Based on a paper presented by H. W. Lefevre and J. T. Russell, Hanford Atomic Products Operation, General Electric Co., Richland, Wash.

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What's New in Photomultipliers? . . .

. . . Spherical Front Ends, Built-In Voltage Dividers

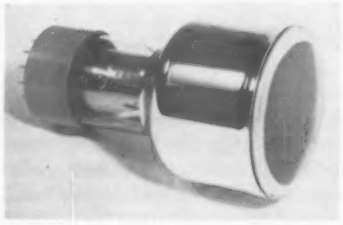
Du Mont is now incorporating spherical "front ends" to decrease transit-time spread. By employing a fully curved tube window in conjunction with a dome-type top shield, a spherical system is approximated. The Du Mont K1549, a 14-stage linear photomultiplier, has such a spherical photocathode. Total transit-time spread is 4 mμsec when using the entire photocathode surface. Accelerators in the first-dynode region serve to reduce the transit-time spread between the first and second dynodes by increasing the field strength in the vicinity of dynode one. A focusing electrode in the region between dynodes one and two deflects secondary electrons leaving the first dynode onto a useful portion of the second dynode. To obtain high peak pulse currents additional accelerator grids have been placed between the last several dynodes. These grids are internally connected to their associated dynodes and reduce space-charge saturation between successive dynodes.

Average electrical characteristics are: photocathode-anode voltage: 1,890 volts; S-11 response; photocathode luminous sensitivity: 60 μamp/lumen; anode luminous sensitivity: 360 amp/lumen; amplification: 6×10^6 (at 105v per stage); equivalent anode dark current input: 2×10^{-9} lumen (max).

Other Du Mont developments include 8- and 12-in. tubes having flat faceplates of lime glass and fused quartz respectively to reduce background from K^{40} in potassium-bearing glasses.

A new photosensitive surface, cesium telluride, provides very low dark current with good ultraviolet response.

Built-in voltage dividers especially designed to give the proper voltage distribution for a particular tube are now available in the form of a printed-circuit capsule potted at the tube base or enclosed in the evacuated tube envelope. In either case no more than three leads need emerge from the base of the tube: two for the positive and negative terminals of the power supply required to operate the tube, and the other for an anode connection.



Du Mont K1562 5-in. tube has linear multiplier structure. Fully curved photocathode leads to reduced transit-time spread and greater collection uniformity

Based on a paper by F. W. Schenkel, Allen B. Du Mont Laboratories, Clifton, N. J.

. . . New Tubes and Photocathodes at RCA

The 6810, first of the commercial high-gain, high-speed tubes, has now been modified (6810A) by a curved face-plate—flat on the outside—to reduce transit-time spread between the photocathode and the first dynode. Another new short-transit-time tube is the 5-in. 7046 with extended S-11 response and 14 Ag-Mg dynodes. The stem has stiff leads and requires no base, this results in short, straight and parallel output connections. Nearly all of the cathode is spherical and the grids and associated geometry between the cathode and multiplying structure are such that good collection is obtained from the entire cathode. Over a 3-in. diameter the maximum transit time difference is less than 1 mμsec. For a typical tube the average collection efficiency is 80%. At the maximum voltage of 3,400 volts, sensitivities between 400 and 7,000 amp/lumen are obtained.

The switch from plane to partially spherical cathode surface was also used on the RCA-6342 and the RCA-6655, which is the same design as the RCA-6342 but has higher-gain Cs-Sb dynodes. The improved versions are referred to by the developmental numbers C7164G and C7189B respectively. The improvement in pulse-height resolution is typically 20% reduction in pulse-width at half-maximum.

The C7251 is a 14-stage photomultiplier identical in design with the 6810A except for the structure above the multiplier cage. The focusing electrode has been made cup shaped to simulate spherical geometry better. The difference in transit times for photoelectrons leaving various parts of the cathode is less than a few tenths of a millimicrosecond over nearly all the cathode areas.

Photocathodes. Multialkali (Sb-K-Na) cathodes, which were a laboratory curiosity at the time of the last symposium (NU, Apr. '56, p. 54), are now a part of developmental tube types C7237 (mechanically similar to the 6810A) and C7261 (10 stages). The new multialkalis have the highest red sensitivity of any photocathode, yet are superior to the S-11 response in the blue region most used for scintillation counting. Dark emission is low and surface conductivity sufficiently high to permit operation at −200° C.

Based on papers by William Widamier and by R. W. Engstrom, et. al., of RCA, Lancaster, Pa.

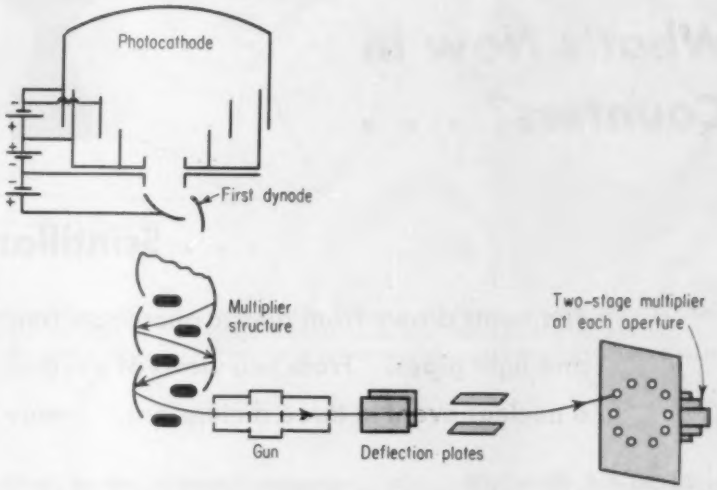
. . . We're Reaching for the Micromicrosecond Region

A photomultiplier incorporating features like those in the composite illustration at right should have a transit-time spread of a few micromicroseconds, two or three orders of magnitude better than any tube available at present. This striking improvement will come from the application of design principles that promise to lick the twin bugaboos of spread in path length and initial velocity in both the photocathode-to-first-dynode and interdynode regions.

The photocathode is made spherical and focus rings provided to simulate the system of concentric spheres that would give truly constant path lengths in this region. This sort of system is currently being used in the C7251. Actual measurement shows a transit time spread under 10^{-10} sec for 90% of the cathode area. In addition the application of voltages of alternating sign as shown serves to reduce the effects of the spread in initial velocity by rapidly accelerating the photoelectrons to a high velocity and then decelerating them as they approach the first dynode.

In the multiplier structure itself the same accelerate-decelerate principle is applied by use of a system of central electrodes all at the same high potential (these are shown in black in the figure). In a typical system with 200 volts between stages the central electrodes might be at 5–6 kv. Electron paths in the interdynode region can be equalized by designing the structure so as to take advantage of the coherency from one pair of dynodes to the next. That is, if an electron which travels over a long path between the first and second dynodes travels over a short path between the second and third dynodes, the net time spread is considerably reduced. Careful study of this question with the aid of "focusing diagrams" that show the relation between initial and final positions on interdynode trajectories makes a net spread of the order of a few micromicroseconds seem reasonable.

Even the dynode-anode region must be redesigned to keep transit time to a minimum. In one of the two output systems being considered, the output electron beam passes at high velocity through a screen-grid directly onto the terminus of a transmission line. The other output system, which is the one shown in the figure, provides means for making the initial time selection within the tube. The output electrons are formed into a beam that is deflected sequentially into each of ten 2-stage multipliers. This time-selecting system cuts down the time-resolution requirements of the outputs by ten.



Photomultiplier for micromicrosecond region minimizes transit-time spread with spherical photocathode geometry and accelerating electrodes. Sequencing output system can decrease time-resolution requirements of subsequent stages

Based on a paper by G. A. Morton, R. M. Matheson and M. H. Greenblatt, RCA Laboratories, Princeton, N. J.

. . . Fatigue of Photomultipliers Is Less of a Mystery

A major installation such as the Savannah River Laboratory has many hundreds of photomultipliers in regular industrial-type service. This makes the "fatigue" of photomultipliers—their variation in gain with use—a subject of major interest.

More than 100 photomultipliers, principally Du Mont 6292's and RCA 6655's and 5819's were studied for periods of at least a week in an attempt to learn something about fatigue. Since fatigue is a current-associated effect, the last dynode, which carries the heaviest current, is first affected. For anode currents of the order of 1 μa and at room temperature (fatigue effects are temperature-dependent though not temperature-induced) peak-to-peak change in gain was of the order of 15%. For anode currents of the order of 0.1 μa the change is only 1%, and damage is restricted to the final dynode. Detailed effects are complicated and vary from tube to tube.

A plausible explanation for fatigue effects is that incident electrons dissociate surface molecules releasing Cs that can then diffuse off the surface. Depending on the intitial Cs concentration and the shape of the gain-per-stage vs cesium-concentration characteristic, the gain will increase or decrease. Temperature and time also enter as factors since they also lead to changes in the surface character and the effect of current thereon.

Based on a paper by L. Cathey, Savannah River Laboratory, Aiken, S. C.

SCINTILLATION COUNTING —1958

What's New in Counters? . . .

. . . Scintillation Track Chambers

Filaments drawn from plastic phosphors function simultaneously as detectors and light pipes. From two views of a rectangular array one can reconstruct a nuclear event in three dimensions. Image intensification is necessary

By GEORGE T. REYNOLDS
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VIEWING THE TRACK of an ionizing particle in a solid scintillator has been discussed by various workers practically from the time that the usefulness of scintillation counters became apparent. Recent developments in the preparation of plastic-scintillator filaments (*1*) has led to renewed interest.

The filaments operate as both scintillators and light pipes. By placing them in a crossed rectangular array and then viewing their ends it is possible to produce a stereoscopic view of a nuclear event.

The system has several advantages over the propane bubble chamber. Its principal disadvantage is the small amount of light produced. This leads to the necessity of very efficient optical systems and the use of an image intensifier with a gain of $\sim 10^5$.

Advantages

The light-piping action of filament arrays has already been demonstrated. If one is placed between a radioactive source and a photographic film, the result is an image of the source much more intense than from a similar arrangement with a solid scintillator in place of the array of filaments.

Actual operation of a scintillation chamber requires improved image intensifiers. Already, however, we have placed a $1\frac{1}{4} \times 1\frac{1}{4} \times 2\frac{3}{4}$ in. array in front of a medium-gain image tube and followed the motion of a weak Co^{60} source on a kinescope fed by the orthicon output of the tube. Interactions in carbon should be distinguishable from those in hydrogen because the range of the secondary particles from the carbon interaction will be short and restricted to the filament in which the interaction occurred thus producing a relatively brighter output. Such a distinction is not as reliably made with a propane bubble chamber.

Other potential capabilities are:

- Fast-timing resolution. The chamber can be used as one element in a fast multiple-coincidence system permitting the selection of events of interest either externally or internally (*2, 3*). It can also act as a counter in the determination of its own visual sensitivity.
- Topologically complicated configurations can be evolved. One can collect on one tube the information from spatially separated regions.
- Data storage. Events can be analyzed and then accepted or rejected in 0.1–100 μsec. Whereas the bubble chamber must deal with postexpansion tracks, the scintillation chamber, with suitably gated phosphors, can decide after the event whether recording should be completed. It is readily adapted to magnetic tape storage of all information obtained.
- Rapid repetition. 10^4 or more pictures per second can be obtained.
- Favorable signal-to-noise ratio. A minimum ionizing particle supplies, for the filaments affected, about 2,000 photoelectrons/cm². The cathode noise is about 5,000 electrons/cm²/sec. The track signal is obtained from a gate of $\sim$5-μsec duration. Thus the signal-to-noise ratio is approximately $2000/(5000 \times 5 \times 10^{-6}) = 4 \times 10^4$.

Scintillator Filaments

Early in 1954 several members of the Elementary-Particles Group of Princeton University considered thin filaments of plastic scintillators as a means of removing the depth-of-focus restrictions inherent in earlier single-crystal track cameras (*2, 3*). The basic idea is shown in Fig. 1. The crossed arrays of filament scintillators

Inorganic Filaments?

The simple nuclear constitution of the plastic scintillator (C and H) is an advantage in many applications. However, several other materials are currently being considered. In view of the much higher scintillation efficiency of CsI, some effort is being devoted to the preparation of long crystals of this material. The possibility of using glass filaments according to an original suggestion of George Morton is again suggested by the recent work of Egelstaff (*9*) and Ginther (*10*). Morton has also suggested the use of NaI filaments.

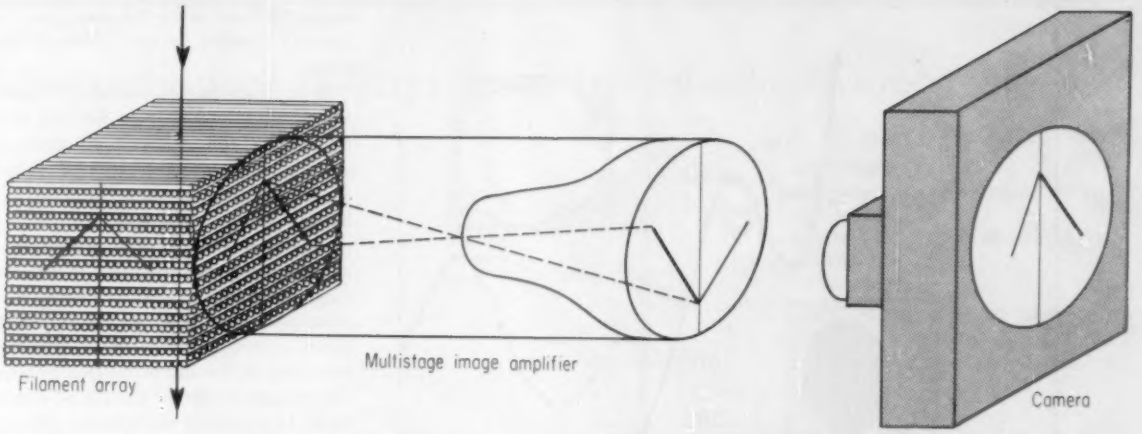

FIG. 1. Rectangular array of crossed plastic-scintillator filaments (left) permits reconstruction of trajectory of high-energy particles traversing it. Light generated in filaments through which particle passes is piped out to ends where mutistage image amplifier boosts signal for recording by camera. Views of two faces permit three-dimensional reconstruction of event

are viewed by two image intensifiers, one for each direction.

Light caused by passage of a charged particle through a filament is piped by internal reflection to the end of the filament (4). Thus, a particle moving through the array causes the filaments traversed to emit light at their ends. Since optics problems are restricted to a plane source, the depth-of-focus problem is eliminated. The two orthogonal views provide the basis for three-dimensional reconstruction.

Filament preparation. The ease with which plastic scintillators can be prepared in the form of long thin filaments has led to the successful construction of several scintillators of this material. The filaments are prepared by melting polymerized plastic scintillator material (polystyrene, 3% terphenyl, 0.1% POPOP) at about 200° C, and then continuously drawing out a filament at a speed to yield a diameter of ~1 mm. At one time, approximately 2,000 yards of plastic-scintillator filament was collected from a very modest apparatus set up in our laboratory. The diameter can be varied fairly easily between 0.5 mm and 1 mm by adjusting temperature and speed.

We chose 0.7 mm for the first configurations tested. Extensive work on filament optics (4) has shown that the effectiveness of light piping is not affected by gradual changes in the shape of the filament cross section.

One serious problem with plastics is that of surface crazing. In the preparation of these filaments we have taken care to prevent vapors, oils, skin, etc., from coming into contact with the surface. These factors are known to enhance crazing. If very-small-diameter filaments are used, many internal reflections are necessary to pipe the light to the end, and the cumulative effect of even slight crazing is serious.

Another important question in the application of these filaments to large particle detectors is light absorption. Preliminary measurements at the Rochester Institute of Optics indicate that 50% optical absorption at 4,400 A occurs in 20 cm of filament (5). One can expect large variations in this figure due to the effects of crazing, but these preliminary results are encouraging.

Phosphor efficiency. Pulse heights from filamentary and solid samples were compared by placing them on a 6342 photomultiplier and recording the distribution resulting from the 624-kev electrons from Cs^{137}. Results are shown in Fig. 2. It is seen that the pulse height from the filament counter is about 54% that from the solid counter. The difference can be explained by the light-piping action. The index of refraction of the plastic scintillator is 1.59. Consequently, only about 19% of the light is piped by internal reflection in one direction. (This fraction can be increased by arranging a reflector at the end of the filaments opposite to the photomultiplier, but this was not done in the present case.)

Previous experience indicates that ~35% of the light is collected in the arrangement used for the solid plastic sample. Thus the expected ratio of pulse heights is $19/35 = 0.54$, as observed. Uncertainties in the 35% figure prevent us from concluding that the remelting has had no effect.

How many photons? On the basis of these results one can determine the number of photons appearing at the end of the filament due to the passage of a minimum-ionization particle. For a 1-mm filament diameter the average path normal to the axis is $2/\pi$ mm. The density is ~1 gm/cm³ so the amount of energy lost by a minimum ionization particle is $(2/\pi) \times 1 \times 2 \times 10^6 = 1.3 \times 10^6$ ev. The number of electron volts per photon in a plastic scintillator is generally accepted as being about 130 ev/photon. Thus the number of photons released by the particle is $(1.3 \times 10^6)/130 = 10^4$. Of these 19% are piped to the end and there distributed over $(\pi/4) \times 10^{-2}$ sq. cm. Thus the number of photons per sq. cm. is $10^4 \times 0.19 \times (4/\pi) \times 10^2 = 2.4 \times 10^6$.

To allow for possible effects from remelting and the uncertainty in the 35% light-collection figure used to evaluate performance, we conclude it is safe to say that 2×10^6 photons/cm² result from the passage of the particle. The number of photons per filament increases with the diameter of the fila-

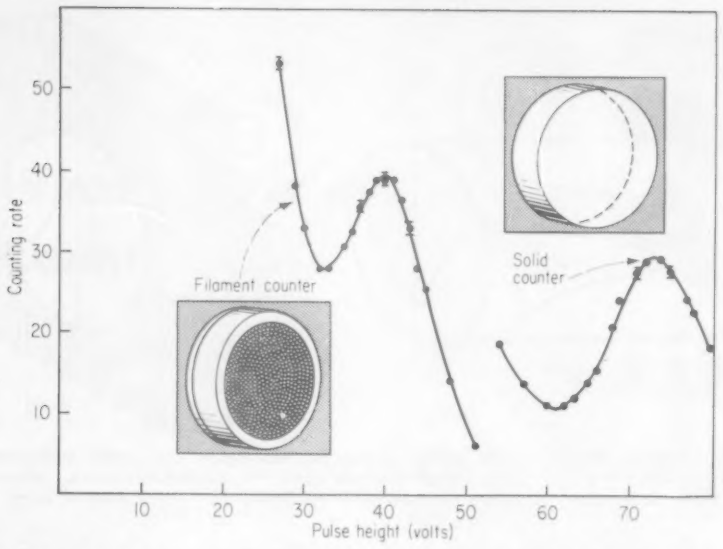

FIG. 2. Pulse heights from filament array are smaller than from solid scintillator of the same size. Losses in light piping explain the difference

ment, but the end area increases with the square so that the intensity goes as the reciprocal of the diameter. Thus thicker filaments are undesirable from this standpoint.

Filament scintillator arrays have been prepared with the following dimensions: 3/8-in. diameter and lengths of 7/8, 1 and 2 in.; 2-in diameter, 3/4-in. length and $1\frac{1}{4} \times 1\frac{1}{4}$-in. square cross section, $2\frac{3}{4}$-in. length.

Scintillation Chambers

We have just seen that the passage of a minimum-ionization particle normal to the axis of a filament results in the emission of 2×10^4 photons/cm² at the end of the filament. One of the most sensitive films available is the Eastman Kodak Royal X Pan, which requires approximately 7.7×10^7 photons/cm² for a developed density of 0.1.

Consideration of minimum contrast for a scintillation-chamber picture indicates that a minimum of 16×10^7 photons/cm² is necessary. Thus a gain of 10^4–10^5 is required in the intensity available from the filaments.

The application of image intensifier tubes to the problem at once suggests itself. Such tubes have been known for some time (*6*, *7*) but generally limited to much less intensification than required here.

The principle of the device is as follows: About 10% of the photons falling on a cathode result in secondary electrons. These are accelerated and focused, either electrostatically or magnetically, on the phosphor in such a way as to preserve the image. The accelerating voltage is ~10 kv, so that each electron gives rise to many photons from the phosphor. Gains of ~30 in the number of photons have been achieved for a single stage. If the size of the image is reduced by the focusing, this represents a further intensity gain for the present purposes so long as the intrinsic space resolution of the recording device exceeds that of the filament array.

To achieve the large (10^5) gain that is found desirable it is necessary to provide several stages of intensification. This can be done by cascading single stages with suitable optical coupling, or by utilizing multistage tubes, containing successive cathode-backed phosphors in a single envelope with suitable focussing. In either case the final phosphor can be followed by an image orthicon or suitable photographic recorder.

Gating. For the tube to be useful in a fast-particle-track-imaging application a suitable gating feature must be included somewhere after the first phosphor. This is to provide the possibility that a complete track-recording sequence can be held off or allowed depending on the information supplied by auxiliary counter circuits after the event of potential interest. Thus it should be possible to decide up to 10^{-7} sec after the passage of a particle whether or not to record the event.

If the decision is to record, the signal should be extracted from the tube in a few microseconds. Such an arrangement could be achieved by a phosphor of several microseconds lifetime followed by a photocathode gated by a grid. This gating arrangement has already been incorporated in certain single-stage tubes. In view of the nonexponential decay of certain phosphors consideration must be given as to where in the intensification process the storage phosphor should be put in order to minimize background pile up.

In view of the proposed application of the tube to filament chambers, sufficient over-all resolution must be available to allow reasonably sharp space reconstruction of particle paths. For this purpose it is necessary that the image-intensifier system be able to resolve two adjacent uniformly illuminated filaments each 0.5 mm in diameter. One of the most promising leads is the possibility of using glass ends made up of light pipes on both ends of the image intensifier. This gives good resolution through thick sections. When this is done, the gain required can be achieved by cascading single-stage units, each unit being much simpler to produce than a multistage unit of the same over-all gain. Account must be taken of the rather high optical losses in the light-pipe windows, which are at least 60%. In view of this loss several optical coupling schemes have been proposed including a regenerative scheme (*8*). In evaluating light losses at an interface involving the scintillating filaments, one should keep in mind that light is probably directed forward more sharply than predicted by Lambert's Law. This is currently being further investigated.

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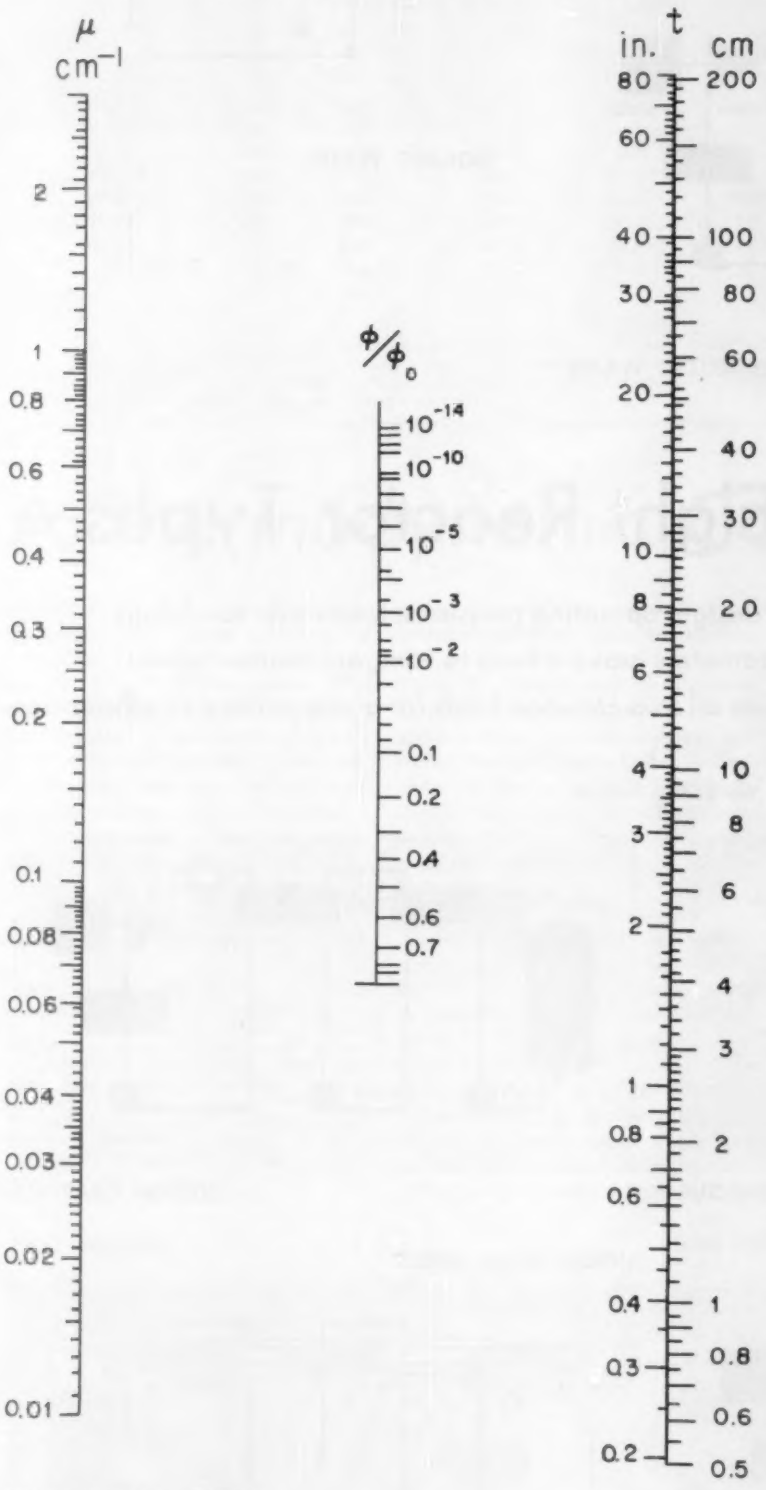
Attenuation of γ-Rays from an Infinite Plane



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FOR AN INFINITE PLANE source of gamma rays the attenuation factor ϕ/ϕ_0 for materials other than lead is given by

$$\frac{1}{2}\left[e^{-b} + E_1(b)\right] \qquad (1)$$

where $E_1(b)$ is a form of the exponential integral (*1*). In the case of lead, the factor is

$$\frac{1}{2}\left[e^{-b} + \frac{E_1(b)}{2}\right] \qquad (2)$$

This nomogram solves Eq. 1 for elements other than lead and for gamma-ray energies to 3 Mev. For lead, one can readily determine the attenuation from Eq. 2.

To calculate attenuation of gamma rays from an infinite plane source, it is necessary to have values for the linear absorption coefficient μ. The linear absorption coefficients can be obtained from curves (*2*) or tables (*3*) of mass absorption coefficients by multiplying by the density of the shield material.

For a shield thickness t, a quantity b is defined as $b = \mu t$. For most elements other than lead, the value $1 + b$ for gamma energies up to 3 Mev (*2*) can be used as an approximation for the buildup factor B.

Example

Problem: How thick must an iron shield be to attenuate the gamma rays from an infinite plane source by a factor of one-tenth?

Procedure: Employing the linear absorption coefficient for iron given by Glasstone (*3*), $\mu = 0.27$ cm^{-1}, draw a line from $\mu = 0.27$ through $\phi/\phi_0 = -0.1$ and read on the t scale the value 6.9 cm.

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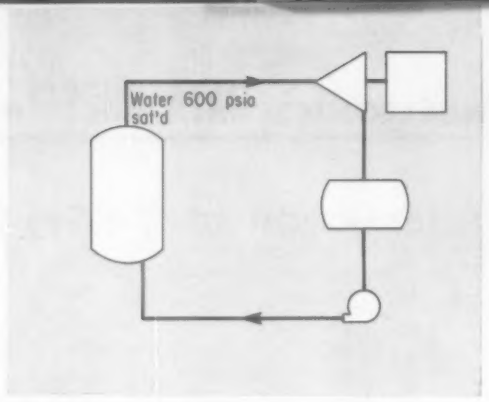
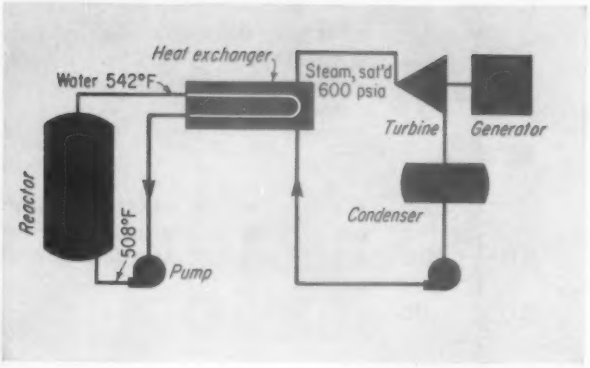


BOILING WATER

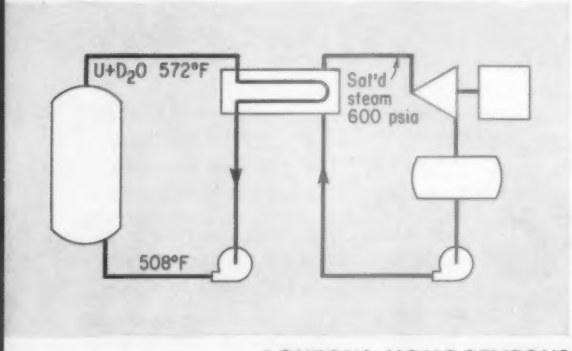


PRESSURIZED WATER

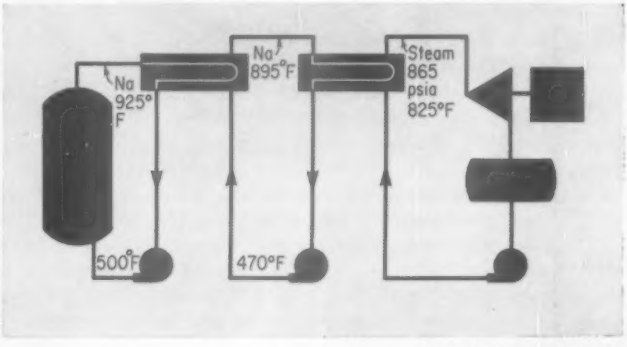
Eight Reactor Types—

Variations in turbine design, operating pressures, feedwater conditions and other design parameters make it hard to compare reactor types. This study adjusts them all to a common basis for a comparison of efficiencies

By S. BARON *Burns and Roe, New York, New York*

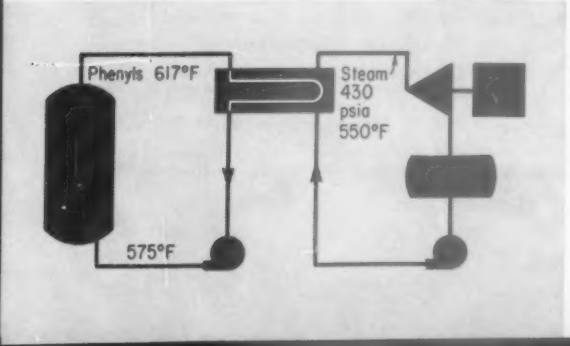


AQUEOUS HOMOGENEOUS



SODIUM GRAPHITE

ORGANIC MODERATED



LIQUID METAL FUELED

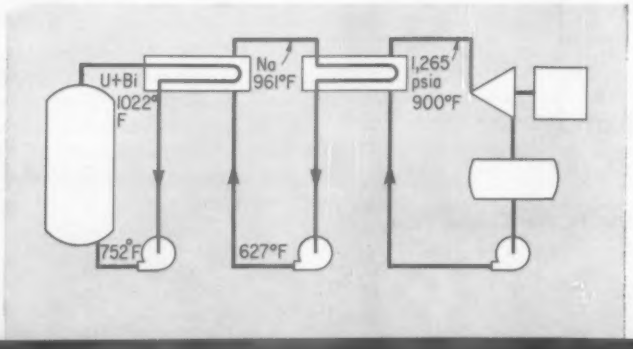


TABLE 1—Thermodynamic Efficiencies of Nuclear Power Plants*

	Adjusted turbine-throttle steam conditions		*Generator output*	*Turbine† heat rate*	*Auxiliary power*	*Net plant heat rate*	*Over-all efficiency*
	Pressure (psig)	*Temperature (°F)*	*(Mw)*	*(10^3 Btu/kwh)*	*(%)*	*(10^3 Btu/kwh)*	*(%)*
EBR-2	1,265	850	111.7	9.2	10.5	10.3	33.1
LMFR	1,265	900	112.5	9.1	12.5	10.4	32.8
SGR	865	825	106.7	9.6	8	10.4	32.8
EBWR	600	486	92.1	11.1	5	11.7	29.2
HRE-2	600	486	92.1	11.1	6	11.8	28.9
PWR	600	486	92.1	11.1	9	12.2	28.0
OMR	430	550	89.8	11.4	11.5	12.9	26.4
Calder Hall	215, 65	600, 372	74.7	13.7	17	16.5	20.7

* Basis to which actual parameters are adjusted for this comparison: reactor heat, 300 Mw; three feedwater heaters; condenser pressure, 1.5 in. Hg; tandem-compound triple-flow 3,600-rpm turbine.

† Turbine heat rate, which is proportional to the reciprocal of steam-cycle efficiency, is the heat generated in the reactor divided by the turbogenerator output.

A Thermodynamic Comparison

ANALYSIS OF THE basic thermodynamics of their power cycles is an important but frequently neglected way to compare reactor types. The eight most advanced reactor types* are compared here in terms of power-cycle efficiency, auxiliary power requirements, feedwater heaters and temperatures and over-all efficiency. Design parameters of operating prototypes have been scaled so as to be properly comparable.

The cycle arrangements of the eight types are shown in the figures on this spread along with the temperature and pressure conditions attributed to these cycles at the time of writing (1957).

On the basis of my assumptions, liquid-metal-cooled reactors have the greatest steam-cycle efficiency and gas-cooled reactors the smallest. Boiling-water reactors require the least auxiliary power. The best over-all efficiency is that of a fast breeder using three feedwater heaters—33.1%.

Over-All Efficiencies

Frequently, the costs of nuclear power are based on the turbogenerator output. Actually the figures should be based on the net power available for sale, after deduction of auxiliary power requirements, which, as will be shown, can be 17% of gross output.

Table 1 tabulates the net plant heat rates of the eight reactor types considered. Of the water-cooled reactors, the over-all efficiency of the boiling-water type is best because of its low auxiliary power requirements.

Of the liquid-metal-cooled reactors, the high auxiliary power of LMFR penalizes its thermodynamic advantage to make it comparable to SGR. EBR-2 still has the best efficiency even though its auxiliary power is high.

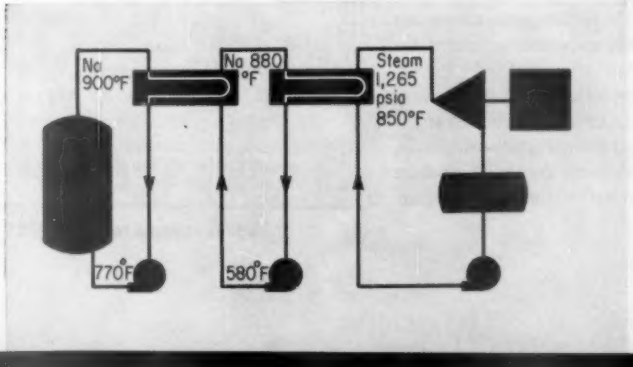
Gas-cooled Calder Hall has the poorest over-all thermodynamic efficiency because of both poor steam conditions and high auxiliary power.

Steam-Cycle Efficiencies

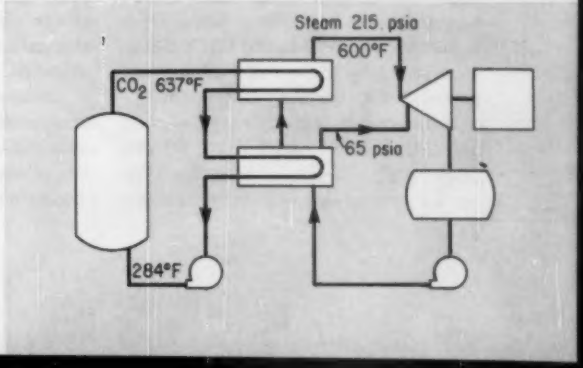
Table 1 also shows the results of a comparison of the efficiencies of the steam cycles. In arriving at these results it was necessary to recognize that published efficiencies are not a valid basis for comparison because of the variation in design parameters such as turbine size, condenser pressure, number of regenerative feedwater heaters, actual turbine design

* The actual plants used as a basis for comparison are: Experimental Boiling Water Reactor (Argonne National Laboratory); Pressurized Water Reactor (Shippingport, Pa.); Homogeneous Reactor Test (Oak Ridge); Sodium Graphite Reactor (Hallam, Nebraska); Organic Moderated Reactor (Piqua, Ohio); Liquid Metal Fuel Reactor (Brookhaven design in 1955 Geneva Conference Proceedings); Experimental Breeder Reactor-2 (Idaho Falls, Idaho); Calder Hall (England).

FAST BREEDER



GAS COOLED



and final feedwater temperature. To compare these reactors on a common basis and determine the effect of the turbine steam conditions, it was necessary to calculate their power-conversion efficiencies.

Assumptions. For all cases the heat supply was assumed constant at 300 Mw. The same basic turbine-efficiency curve is used for all the calculations with appropriate corrections for steam volume flow, superheat, exhaust losses and moisture content. Condenser pressure is assumed constant at 1.5 in. Hg absolute. The turbine type is a tandem-compound triple-exhaust flow unit at 3,600 rpm. In each case I assumed three feedwater heaters with a final feedwater temperature of 300° F.

All the reactor types show a turbine heat rate about 1,000 Btu/kwh lower for three feedwater heaters than for a cycle without such heaters. As discussed later, other factors connected with steam generator design may make the higher feedwater temperature uneconomical, but thermodynamically the gain is appreciable.

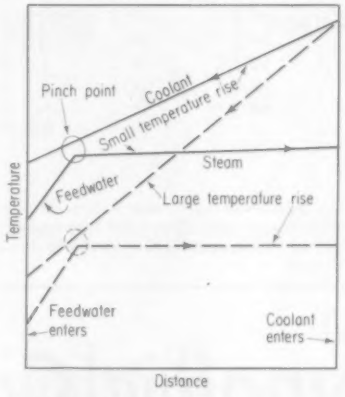
Water-cooled reactors. Pressurized-water, boiling-water and aqueous homogeneous reactors were all assumed to generate saturated steam at the same pressure. (Actually there are small variations among the prototypes, PWR, EBWR and HRE-2.) A moisture separator was considered in the calculations of the turbine efficiencies to prevent the moisture content from increasing above 12%, which would give a highly erosive condition in the turbine.

A dual cycle with part of the steam generated at lower than 600 psig will result in a poorer turbine heat rate. However, this loss can be eliminated by generating primary reactor steam at pressures above 600 psig, as is done in the Dresden reactor.

Organic-moderated design. OMR is less efficient than saturated-steam units because of lower steam pressure. Increasing steam pressure and temperatures to values shown for water-cooled reactors would give this reactor type the same cycle efficiencies. There is nothing inherent in the OMR design that prohibits the use of higher steam pressures for thermodynamic gain.

Liquid-metal-cooled reactors such as SGR, LMFR and EBR-2 all give power-cycle efficiencies near the average for present-day conventional power plants. The variation in steam conditions reflects the extent of the developmental work at the time of the specific reactor design. In time all three liquid-metal-cooled types should be capable of producing about the same steam conditions.

Gas-cooled reactor. Calder Hall has the poorest steam-cycle efficiency.



PINCH POINT limits improvement in efficiency available by lowering coolant inlet temperature. Curves show temperatures of reactor coolant and secondary fluid as they flow through heat exchanger in opposite directions

This is due to the rather low steam pressures developed for power generation. In the advanced versions of this reactor type, steam pressures have been increased to produce efficiencies comparable to those of water-cooled reactors.

In actual practice, of course, optimum steam conditions for all reactor types are determined by balancing higher capital cost in heat exchangers and other accessories against thermodynamic gain.

Auxiliary Power

Frequently little attention is given to auxiliary power requirements when discussing the merits of various reactor types. Thermodynamically higher steam pressures and temperatures increase the electrical generation for the same heat output of the reactor, but this also requires greater pumping power for the feedwater pumps, so the gain is not as great as might be expected.

Coolant properties and heat-removal arrangement have an appreciable effect on auxiliary power demands and, thus, net power available for transmission. To appreciate better the relative magnitude of auxiliary power requirements for the reactor types of our figures the summary in Table 2 was developed. It is based on the steam conditions and cooling cycles shown. The boiling-water type was used as the base case. The only variables considered were feedwater- and cooling-pump requirements. All other power requirements were considered unchanged. Coolant flow rates and heads were based on published literature, with flow adjusted to the same electrical output. Where pressure drops were lacking, pumping heads of related reactors were used and, if necessary, corrected for velocity and core length.

Boiling-water reactors have the lowest auxiliary-power requirements because the condensate pump, common to all cycles, also serves as reactor coolant pump. In the dual cycle arrangement of the boiling-water reactor, the auxiliary power is increased approximately 0.5% owing to forced-circulation pump power requirements. Of the water-cooled reactors, the pressurized-water type requires the greatest coolant-pumping power because of the high water velocities necessary for heat removal in a relatively small reactor. The organic-moderated reactor, which is comparable in size to the water-cooled, has even greater pumping requirements because of the poorer heat-transfer properties of the coolant.

Liquid sodium is an excellent reactor coolant, but it also has a low specific heat. Therefore, the pumping requirements for sodium are greater than for water at the same velocity

TABLE 2—Auxiliary Power Requirements

	Power required (%)*		
Reactor	*Coolant pumps*	*Feedwater pump*	*Total*
EBR-2	4	3.5	10.5
LMFR	6	3.5	12.5
SGR	1.5	3.5	8
EBWR	0	2	5
HRE-2	1	2	6
PWR	4	2	9
OMR	7	1.5	11.5
Calder Hall	13	1	17

* Other auxiliaries are assumed to require 3% of the output in every case.

TABLE 3—Feedwater Conditions of Reactor Prototypes

Reactor	Steam conditions: Pressure (psia)	Steam conditions: Temperature (°F)	No. of heaters	Final feedwater temperature (°F)
PWR	620	(sat.)	3	325
EBWR	615	(sat.)	0	110
HRE-2	520	(sat.)	1	180
SGR	815	825	3	300
OMR	430	550	3	337
LMFR	1,265	900	6	475*
EBR-2	1,265	850	5	450
Calder Hall	200	590	0	100
	53	340		

* Proposed in advanced design.

and temperature. Some attempt is made to reduce pumping power by designing for larger temperature rises in the reactor. However, the extent of the rise must be limited by the thermal stresses that develop. Overall pumping-power requirements are increased even further by use of two sodium or NaK circuits in series in order to separate radioactive sodium from the steam circuit.

Fast reactors, since they have high power densities, require exceptionally high coolant velocities and even more pumping power.

Gas-cooled reactors of the Calder Hall type have very high auxiliary-power demands because of poor heat-transfer properties and low density of the CO_2 coolant. Finned fuel-element design improves heat transfer but also increases head losses. Pumping the gas under high pressures will decrease the pumping requirement, but the requirement is still appreciable.

The feedwater-pumping powers of the various cycles all reflect to a major extent the greater head requirements necessary for the higher steam pressures. A smaller effect, which reduces the feedwater pumping power somewhat, is the reduction in the feedwater flow rate with higher thermodynamic efficiencies. However, this gain is far outweighed by the pressure consideration.

The reduction in the condenser water-circulation pumping-power requirements with the higher efficiency cycles was neglected because this power requirement is generally about $\frac{1}{10}$ of that of feedwater or coolant pumps.

Feedwater Temperatures

In conventional boilers high final feedwater temperatures increase the heat-sink temperature, thereby requiring either more surface in the boiler or greater heat loss in flue gases. Generally, high fossil-fuel costs have justified the greater investment in surface for feedwater heaters and boilers in return for improved efficiency with the thermodynamic optimum in final feedwater temperature.

In nuclear power plants, all the heat generated in the reactor is available for steam generation. However, the steam temperatures obtainable depend on the maximum permissible coolant temperature. Heterogeneous fueled reactors, designed with uranium metal, are limited in fuel temperature by the solid-state phase change at 1,220° F which produces fuel-element distortion. Taking into account the temperature drops through the generally poorly conductive fuel and its cladding, maximum coolant temperature obtainable would not be much greater than 1,000° F.

A secondary limitation on maximum coolant temperature is the availability of structural materials to stand the highly radioactive and usually corrosive reactor-core environment. For this reason even homogeneous liquid-metal reactors are limited in their maximum permissible temperature.

With these metallurgical requirements limiting maximum coolant temperature, one method of increasing the heat generation for a fixed core size at constant coolant velocity is to lower inlet coolant temperature. However, this reduces maximum possible steam pressure, thereby decreasing steam-cycle efficiency. This phenomenon results from the so-called "pinch point," which is the minimum temperature difference between coolant and generated steam. Lower coolant temperature at the reactor inlet also requires a lower final feedwater temperature, which decreases the regenerative cycle efficiency. The figure on page 66 shows the temperature traverse in the steam generator with two values of temperature rise in the reactor.

Heat output of the reactor can be increased by increasing the circulating rate of the coolant. However, part of this gain is lost either in the greater pumping requirements for a fixed core size, or in the increased reactor size for a fixed velocity.

One way of circumventing the "pinch point" limitation would be to generate the steam at a number of increasing steam pressures, as in Calder Hall, so that the low-level steam temperatures could be utilized by admission to the lower-pressure stages of the turbines. The thermodynamic gain of such a procedure must be balanced against the increased cost of the steam generator.

Table 3 reviews the actual final feedwater temperature of various reactors and indicates an appreciable spread in values, all, presumably, economically evaluated.

* * *

I would like to acknowledge my appreciation to the Burns and Roe Thermodynamics Section under Mr. I. Gabel's supervision for assistance on detailed calculations of steam-cycle efficiencies.

How About Superheat?

Oil-fired superheaters have been proposed and are being installed in saturated-steam units to increase the steam-cycle efficiency. Superheat is desirable since it decreases the erosive effect of moisture in the exhaust steam and also gives higher thermodynamic efficiencies. In this case turbine heat rates include the heat output of the superheater as well as the reactor. The table below shows that an appreciable improvement in cycle efficiency is possible with superheated steam.

	Saturated	*Superheated*
Pressure (*psia*)	**600**	**600**
Temperature (*°F*)	**486**	**825**
Generator output (*Mw*)	**92.1**	**104.1**
Turbine heat rate (*10^3 Btu/kwh*)	**11.1**	**9.8**

On Dec. 2, 1957 Argonne reactor engineers walked into the EBWR control room and proceeded to do something unheard of in power reactor circles—they turned on a reactor designed to run at 20 Mw(th) and deliberately ran the power up to 46 Mw(th). Since then, without any changes in reactor design, EBWR has been pushed to a record of 62 Mw (NU, April '58, 25), more than three times the original design output. This new power level automatically reduces EBWR's power cost (see box) by an impressive 40%. One of the men with primary responsibility for the job explains the engineering magic that enabled Argonne to pull three reactors out of the hat where only one went in.

Upping EBWR's Power

By JAMES A. DeSHONG, Jr. *Argonne National Laboratory, Lemont, Illinois*

THE ORIGINAL POWER RATING of 20 Mw(th) for the Experimental Boiling Water Reactor (EBWR) was determined from considerations of reactor stability rather than heat-transfer limitations. At the time EBWR was built experience with the existing boiling-water reactors could guarantee operational stability only for power densities (void volumes) up to those corresponding to 20 Mw(th) operation. Early EBWR operating experience showed that this limit was conservative and that the plant might have considerable power in reserve. For this reason the first major experimental effort was to determine the maximum stable operating power for the first core.

The program was divided into four parts: First extensive power-response measurements were made with a reactivity oscillator at powers up to 20 Mw. Then an expression for the power-to-reactivity feedback transfer function was chosen that gave the best fit to the data. The transfer function was extrapolated to higher powers and was examined theoretically for stability in the region of 40 Mw(th). Finally, after minor preparations for the larger heat removal, the reactor was taken up to the proposed new power level.

In the process, a good theoretical model of the reactivity feedback loops and a method for predicting stability of boiling-water reactors at higher power levels have been developed.

Oscillator Measurements

As stated, the first phase of the program was to measure the reactor power transfer function* as a function of frequency for different values of power parameters within the limits prescribed by the safeguards report (*1*).

The power transfer function, P_1, can be written simply as the zero-power function G modified by the power-to-reactivity feedback, H_1

$$P_1 = \frac{G}{1 + GH_1} = \frac{\text{flux output}}{\text{reactivity input}} \quad (1)$$

* Transfer function as used here is defined as the amplitude and phase relation of the sinusoidal variation in flux or power output with respect to the sinusoidal reactivity input (driving function).

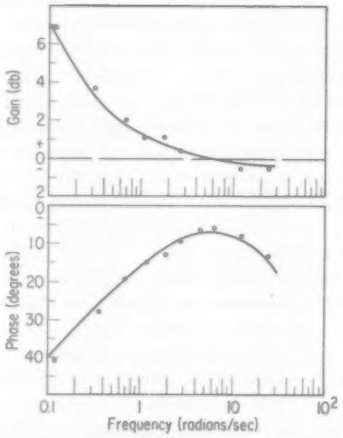


FIG. 1. Zero-power transfer function measured as function of reactivity oscillator frequency. Gain ordinate is equal to 20 log $(N_p\beta_T/N_o\delta K_p)$ where N_p/N_o is fractional power variation caused by fractional reactivity input amplitude δK_p and β_t is total delayed neutron fraction. Phase ordinate gives phase of N_p with respect to δK_p. Smooth curve was predicted from theory

G and H_1 are frequency dependent and H_1 also depends on reactor power parameters. Several techniques can be used to determine the stability of the operating mode represented by P_1 (*2–5*).

P_1 could be calculated and stability predicted if H_1 were known. However, H_1 is difficult to determine from thermodynamic data, and specific measurement of the open loop is not feasible. The method used was to measure P_1 and calculate H_1 using Eq. 1.

The first experiment measured G (that is, P at zero power). The experimental points are compared with the theoretical curve in Fig. 1 (*8*).

During this phase work was done to devise a theoretical model to explain the experimental results and to guide further measurements (*6, 7*). A simplified power-to-reactivity feedback diagram of the model chosen for EBWR is shown in the box on p. 71. Each H in the figure is a transfer-function representation of a power effect.

Investigation of EBWR pressure effects indicated that at frequencies in excess of 2 or 3 radians/sec the pressure feedback loop H_p can be neglected, leaving only the power void loop H_v since feedwater input C is held constant. Preliminary tests without automatic pressure control showed that the frequency of maximum resonant-peak response was in excess of 5 radians/sec, so that the peak response is almost independent of pressure variation. System stability, which can be expressed in terms of this peak response, can then be determined without automatic pressure control by using a reactivity driving function at A and measuring the flux nv.

For high frequencies H becomes very small (since the power feedback can no longer follow fast enough) and P approaches G. Thus very accurate measurements are needed to calculate H for this frequency region.

The reactivity forcing function was generated by a special rod drive that replaced the regular central-control-rod drive. A variable-displacement bell crank was driven by a combination of mechanical and hydraulic transmissions to cover a frequency range of 0.01–25 radians/sec. The connecting rod was very long compared with crank displacement; therefore, the control rod stroke was an accurate sinusoid, producing the desired sinusoidal reactivity variation. Static pressure and weight forces in excess of 600 lb and comparable inertial forces were neutralized by a spring that biased out the static forces and resonated with the inertia to reduce drive horsepower requirements to a reasonable value.

The amplitude of the reactivity input was limited by both the reactivity-drive power requirements and the necessity for maintaining a small input to preserve linearity (*8*). Thus, the output flux signal often had a peak value of less than 5% of the average flux value. Since the "boiling noise" in the reactor flux output ranged up to a peak value of 5%, or more, of the average flux value, the signal-to-noise ratios were less than one in some cases. To detect a ±5%-amplitude or a ±2-deg phase change of the flux signal under such unfavorable circumstances, a wave analyzer was used to measure only the fundamental component of the flux signal and compare it with the reactivity forcing function (*9*).

To make meaningful comparisons of power response at different power levels there must be some assurance that the

Lowering EBWR Power Costs

In raising EBWR's power from 20 Mw to 60 Mw Argonne engineers effected what is without doubt the most sudden and drastic improvement in power costs yet seen by the industry. Last summer EBWR's designers reported a total power cost of 52 mills/kwh at its design power of 20 Mw(th) (see table and NU, July '57, 52). Now that the original investment can be charged against a factor-of-three greater power output, all costs per kwh with the exception of fuel costs will decrease to roughly one-third of their former value. As shown in the second column of the table (which includes some additional investment for the extra power-generating equipment necessary to operate at 60 Mw) the new power cost comes to 32 mills/kwh. The breakdown of this figure in the table indicates that almost 70% is chargeable to fuel; thus, any future improvement in fuel cost will significantly reduce the total cost.

The last column in the table refers to a proposal for a 240-Mw multiple unit plant made by J. M. Harrer, EBWR Project Manager. The plant would consist of four 60-Mw(th) reactors with assumed total electrical output of 60 Mw(e). The costs shown are based on lowered fuel-fabrication cost due to the factor-of-four increase in volume, and on a 10,000-Mwd/ton fuel burnup obtained by a small increase in enrichment. The 12-mills/kwh figure is attractive, even today.

	EBWR Power Costs (mills/kwh)*		
	20 Mw	*60 Mw*	*240 Mw (multiple unit)*
Capital	22‡	8.5†	6†
Operation and maintenance	8	2.5	1
Fuel fabrication (initial)	4	3	1.5
Uranium rental	1	1	1
	35	15	9.5
Fuel burnup (2,000 Mwd/ton)	6	6	1.5
Annual fabrication	11	11	1.1
	17	17	2.6
Totals	**52**	**32**	**12**

* Cost-basis plant factor is taken as 80%.
† Construction cost $300/kw installed capacity, annual charge at rate of 15%.
‡ $4,628,100 (~$1,000/kw) at 15%.

reactivity oscillator feeds in a known effective reactivity variation at each power level. In practice this is not true since rod worth depends on the void conditions in the reactor. To correct for this the data were normalized by arbitrarily requiring that the power transfer function equal the zero-power transfer function at a frequency of 25 radians/sec.* This method was subsequently justified by calculations on the H function.

Typical power transfer functions measured for EBWR are shown in Fig. 2. The curves in Fig. 2a demonstrate the effect of a four-fold increase in power level at constant pressure. Some resonance peaking occurs in both gain curves, the amount increasing with increased power.

If pressure were held constant so as to reduce H_p to zero, the curves would rise to an asymptotic value only slightly larger than that at 1 radian/sec. The dip at 1 radian/sec becomes deeper with rising power because the steam voids make H_v more important. The peak-response frequency rises with higher power mainly because of a reduction in the time constants of H_f and H_v brought about by changes in reactor coolant flow and steam void content in the core. At the high end of the frequency range both H_v and H_p become ineffective and the curves join as they return to follow G.

The curves in Fig. 2b show the effect of a four-fold *decrease* in reactor design pressure while holding power constant. There is a higher resonance peak and the peak response frequency is higher just as for a power increase. In fact, this curve is strikingly similar to the 20-Mw(th) curve of Fig. 2a throughout the resonance region. The explanation is that the steam void volume has been enlarged by the pressure reduction so that the void condition is approximately the same as at 20 Mw and design pressure.*

Figure 2c shows the effect of lengthening the core. (The effective core length was increased by adding boric-acid poison to the reactor water so the control rods could be withdrawn.)

Phase. Up to this point nothing has been said about the phase curves, which, combined with the gain curves, give the complete transfer function. The accuracy of the phase measurement permitted its use as a check on the shape of the gain curves. Application of the minimum-phase-shift theorem requires that the phase shift be equal to the slope of the amplitude curve except as modified by a weighting function (*10*). The effect of the weighting function is frequently nearly unity so that zeros in the phase curve

* A possible method of measuring reactivity in voids without resort to rod calibrations employs a simplified version of this process. A static measurement of P_1 is made, followed by a measurement at a frequency sufficiently high to insure that P_1 is equal to G. The absolute static value of P_1 is obtained by calculating the value of G for the frequency above and multiplying it by the ratio of the two measured values. It can be seen that the value obtained is $1/H_1$ by considering Eq. 1 for $GH_1 \gg 1$.

The measurement is incremental by definition, so the slope of the curve of void reactivity vs power is obtained by dividing H_1 by the power (in Mw). The reactivity in voids for a specified power can be obtained by plotting and integrating slopes measured for several lower powers, all at constant pressure. The curve obtained by this means is essential for predicting reactor kinetics at increased powers, since it provides the gain factor for the feedback loop as will be shown.

* In terms of the model the open-loop (GH_v) gain for the two cases is nearly equal through the high-frequency region, because the reactor forward gain K_G is directly proportional to the power change, while the feedback gain K_H is roughly inversely proportional to the pressure change. The correspondence is limited to the high-frequency region where H_v is the controlling factor. The peak responses occur at nearly the same frequency for both cases indicating that the feedback time constants are very nearly equal. The above observations led to the development of a method of extrapolating the transfer function, discussed later.

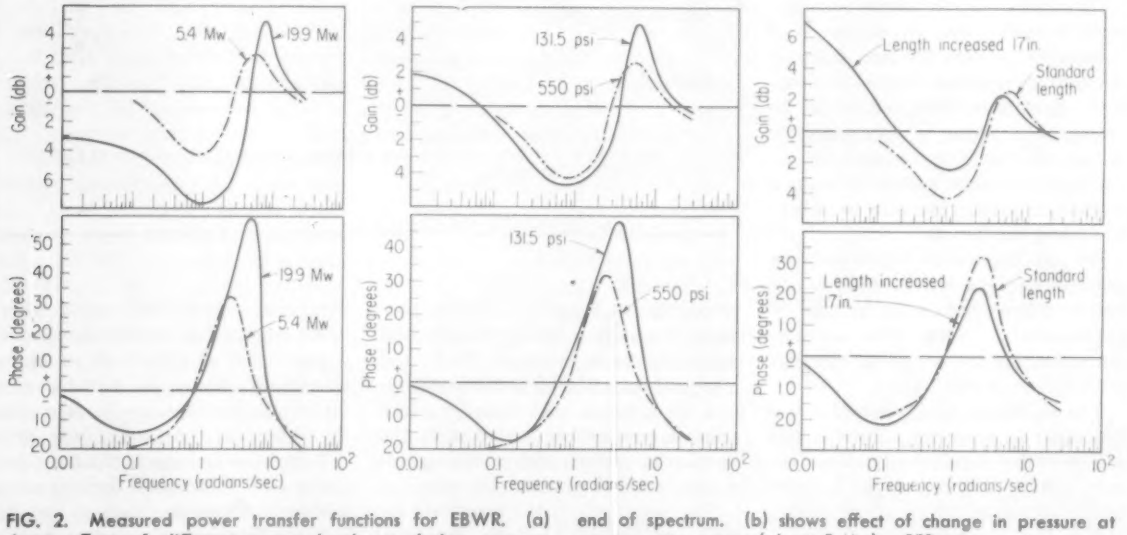


FIG. 2. Measured power transfer functions for EBWR. (a) shows effect of different power levels at design pressure (550 psi). Gain-curve shape above 1 radian/sec is largely result of the power void effect H_v acting without H_p. As frequency decreases below 1 radian/sec, pressure void effect H_p becomes large with respect to power void effect H_v causing net feedback to decrease. H_p continues to increase with decreasing frequency as shown by increasing P gain at low-frequency end of spectrum. (b) shows effect of change in pressure at same reactor power (about 5 Mw). 550-psi curve is same as 5.4-Mw curve in (a). (c) shows effect of different core length at same power (~5.5 Mw) and pressure (550 psi). While height of peaks is same, decreased closed-loop gain P at low frequencies indicates more reactivity in voids for shorter core. These facts suggest heat-transfer time constants are longer for long core possibly owing to decreased flow rate

correspond to maxima or minima of the amplitude curve while maxima and minima on the phase curve correspond to maximum slopes.

The results obtained in this first phase of the program established that the frequency response of a boiling reactor could be measured with sufficient accuracy to make an analytical investigation worthwhile. It also laid the groundwork for a method which permits a safe approach to power by utilizing reduced pressure measurements.

Feedback Transfer Function

In the second phase of the program the experimental data were analyzed to evaluate the importance of the various parameters of the theoretical model and to determine how effectively the model represented the reactor. The first problem was to find the best method for calculating the experimental feedback function H_1 from the power transfer-function data.

Significant uncertainties in determining H resulted from uncertainty in the peak value of reactivity input oscillation and the fact that the feedback function is sensitive to small errors in P at high frequencies. A conformal transformation plane relating GH_1 to $1 + GH_1$ was devised* to inspect the curve shape at high frequencies and permit smoothing of data where obvious discrepancies existed. The plane proved a very useful tool in resolving the uncertainty in power-transfer-function gain because gain change on the plane could be accomplished by simply slipping the entire curve up or down along the $1 + GH_1$ magnitude coordinate.

As mentioned earlier at frequencies above 2 radians/sec it is possible to neglect the H_p loop and consider only the power-void loop H_v. This simplification allowed the feedback H_v to be represented by a function with a constant numerator and a cubic denominator, the exact values of the function being determined by a process involving successive approximations.

For example, the H_v function for 20-Mw 300-psi operation is

$$H_v = \frac{10.1 \text{ decibels}}{(1 + 0.23s)(1 + 0.14s)(1 + 0.06s)} \quad (2)$$

The three time lags 0.23, 0.14 and 0.06 sec represent the time required for the heat to pass from the fuel element into the coolant and the time required for the steam generated by that heat to travel to the core exit.

An analog-computer study of the model was made at the Princeton Computation Center upon completion of the work on H_v functions. The purpose was to evaluate the effects of the pressure-dependent portions of the model and determine how well the model represented the reactor in this area. One finding of the study was that the temperature coefficient was effective only below 0.01 radians/sec so this portion of the pressure feedback was dropped out, which meant that an analytic expression could be used for the entire power-feedback expression. Another result was verification of the assumptions made earlier to obtain the H_v functions. However, the model still did not represent the reactor very well at frequencies below 1 radian/sec.

An analytic expression for the feedback transfer function of the model, a quadratic numerator with quintic denominator, was developed as a

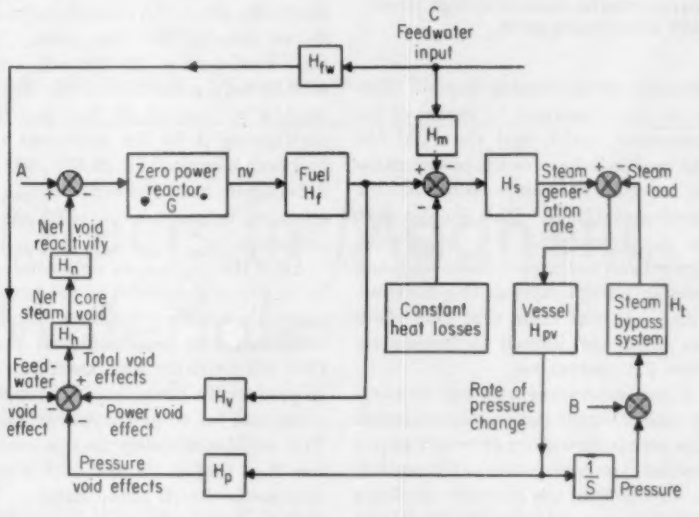
* By W. C. Lipinski, ANL.

EBWR Power-Reactivity Feedback

The diagram shows the theoretical model relating power and reactivity. The H's are components of the over-all power-reactivity feedback function H.

H_{fw} is the effect on voids of core subcooling by the feedwater. H_m is the heat consumed in feedwater heating after injection. C represents the feedwater injection, which is held constant at the average rate of flow required for the power output level of a particular experiment.

H_f is the heat transfer characteristic for heat flow from the generation inside the fuel element to absorption in the coolant. It includes the factor relating heat generation and flux. H_v is the relation between power and steam or void formation internal to the core. H_s determines steam generation from the net heat. H_{pv} represents the pressure-vessel characteristics that determine rate of pressure change when steam generation rate and steam load are not equal. H_{bs} is the dynamic characteristic of the automatic bypass system. (Reactor steam load was controlled by manual bypass so H_{bs} had zero input.) H_p is a complex function that represents the void effects due to pressure. These include temperature coefficient, flashing, and void boundary change. H_h is the natural recirculation dynamic effect on total void which determines the net core steam void. H_n is the relation between net void reactivity and net core steam void. A and B represent external automatic control input.



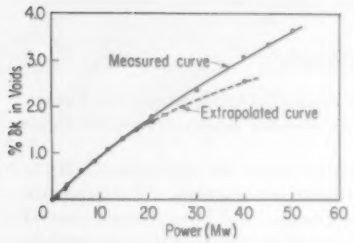


FIG. 3. δK in steam voids as a function of reactor power. Extrapolated curve was 15% lower than subsequently measured curve at new high power level

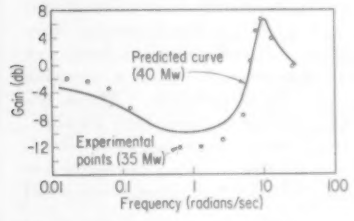


FIG. 4. Comparison of calculated power transfer function at high power with experimental points

follow-up of the analog study. Constants were evaluated by means of the theoretical model, and the IBM-650 was used to determine the power transfer function for comparison with the experimental data. This showed that the discrepancies at low frequencies were related to the part of the feedback transfer function representing the valve orifice. It was clear that this effect was small and limited to frequencies below 0.01 radian/sec.

A new expression with one numerator time constant and four denominator time constants was set up which gave a successful representation of the reactor. As an example, the complete feedback transfer function for the 20-Mw 300-psi condition is

$$H = \frac{+1 \text{ decibel } (1 + 7.7s)}{(1+3.2s)(1+0.23s)(1+0.14s)} \times \frac{1}{1+0.06s} \quad (3)$$

The two time constants added to Eq. 2 to obtain Eq. 3 are determined by complex expressions containing several of the model parameters. The experimentally derived H functions were used to calculate values for these parameters and to correct the model. The model at this point was an accurate representation of the reactor, and could be used to determine the transfer function and stability at increased power.

Extrapolation to 40 Mw

I have mentioned that at reduced pressure the steam void condition in the core is nearly the same as that for a power increase by the reciprocal of the pressure ratio. This effect was used to obtain the time constants for heat transfer, steam transit and water recirculation at 40 Mw and 550 psi by making measurements at 20 Mw and 300 psi. Coefficients depending upon steam properties were extrapolated by direct calculation. The extrapolation of the curve of reactivity-in-voids versus power was (see Fig. 3) determined by a hot, nonboiling rod calibration (*11*). The reactivity void coefficient, which sets the gain of the feedback transfer function, is then the slope of this curve. The 40-Mw condition was obtained by using rod position to evaluate the reactivity change between 20 Mw, 600 psi and 20 Mw, 300 psi and then correcting for the temperature reactivity effect. A smooth curve was drawn through the new point. The void coefficient at 40 Mw was evaluated by taking the ratio of the slope at 40 Mw to that at 20 Mw and then multiplying it by the coefficient that had been measured for 20 Mw, 600 psi. Subsequent measurements proved the estimate to be within 16% of the correct value.

All of the above data were combined by means of the model to produce the required 40-Mw feedback transfer function. This was combined (using IBM-650) with the zero-power function to produce the power-transfer-function prediction for 40 Mw shown in Fig. 4. The 40-Mw stability was somewhat less than that at 20 Mw with a small decrease in the *GH* phase margin. The resonance peak magnitude, however, was only about 2 db above that at 20 Mw.

High-Power Operation

At this point a careful survey of the plant was made to determine feasibility of heat removal, fuel-element-burnout safety factor, and possible hydrodynamic instabilities. The results were combined in an application to the AEC for permission to operate experimentally at powers up to 50 Mw with the present core. The AEC approved the application after careful study of the data that was presented to support it. In the meantime preparations to instrument the increased flows were completed and the plant was ready for the test. On December 2, 1957 the first high-power run was made using the reactivity generator to perturb the reactor at 5, 10, 20, 30 and 40 Mw. The maximum power on this run was limited to 46 Mw, because the hotwell level was behaving erratically and there was a possibility that the feedwater pumps might be cut off by the low-level interlock that protects the pumps from cavitation. On December 9, after the hotwell and turbine problems were solved, the reactor was brought to xenon equilibrium with rods all out, and transfer functions were run at 35 Mw, 550 psi and at 25 Mw, 300 psi. Experimental data for the 35-Mw, 550-psi run are plotted as circles in Fig. 4. Finally on December 23 a short run was made at 50 Mw without Xe to test the mechanical capabilities of the plant and run a transfer function. The open loop *GH* functions were calculated for the various powers and the log polar plane was used to determine gain and phase margins. Extrapolation of a plot of these values vs. power indicated that the reactor would remain stable to at least 66 Mw (*12*). The AEC granted permission for a test run to 65 Mw, and on March 20 a power level of 61.7 Mw was obtained with feedwater flow at maximum capacity. Short power increases to about 65 Mw, obtained by permitting small decreases in reactor water level substantiated the extrapolation.

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TABLE 1—Properties of Magnetic Materials

Material	*Nominal composition*	*Heat treatment* (°C)*	*Core structure*	*Major use*
3.5% silicon iron	3.5% Si, 96.5% Fe	FH 825 FC in hydrogen	Ring laminations 2″ o.d. × 1⅝″ i.d. × 0.014″ thick	Transformers, rotating machinery
Orthonol	50% Ni, 50% Fe	CR RH 1025 RC in hydrogen	Tape-wound toroid 0.002″ thick	Magnetic amplifiers
5-79 Molybdenum Permalloy	5% Mo, 79% Ni, 16% Fe	FH 1300 Cool at controlled rate in hydrogen	Ring laminations 2″ × 1⅝″ × 0.014″	Highest-permeability cores
2 Vanadium Permendur	2% V, 49% Co, 49% Fe	FH 850 FC in hydrogen	Ring laminations 2″ × 1⅝″ × 0.014″	Highest magnetic saturation
16 Alfenol	16% Al, 84% Fe	FH to 1000 FC to 600 RC in hydrogen	Ring laminations 2″ × 1⅝″ × 0.014″	Nonstrategic material substitute for 4-79 Molybdenum Permalloy, Mumetal
Nickel-ferrite	$NiO \cdot Fe_2O_3$	FH 1350 FC in air	Ceramic ring	High-frequency chokes and transformers
2-81 Molybdenum Permalloy	2% Mo, 81% Ni, 17% Fe	FH to 650 FC in hydrogen	Pressed powder ring	High-frequency chokes and transformers

* Symbols: CR = Severely cold rolled; FH = Heated with furnace; FC = Cooled with furnace; RC = Withdrawn rapidly from heat zone; RH = Rapid heat.

Radiation Effects in Magnetic Materials

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MAGNETIC-PROPERTY changes induced by reactor radiation are important to people who want magnetic devices to operate in such an environment. They also have implications for solid-state studies.

We have measured the changes in seven commercial magnetic materials described in Table 1. Tables 2–4 show our results. Almost all samples show deterioration in their magnetic properties. This is to be expected since they are manufactured for optimal magnetic characteristics. However, magnitudes of effects vary considerably from one material to another.

Our results show that designers must not assume that magnetic materials will be generally satisfactory in devices that must operate in radiation environments with constant response. On the other hand, some materials are quite stable. Permendur appears to be promising for magnetic-amplifier cores subjected to radiation and heat—with the important drawback that its cobalt leads to considerable induced activity.

5-79 Molybdenum Permalloy and Orthonol show the most significant changes. At the other extreme, 3.5% silicon iron, 16 Alfenol, and 2 Vanadium Permendur show the smallest ones. One sample especially treated to produce poor magnetic properties was improved by the radiation. The changes appear to be permanent ones.

Magnetic properties are insensitive to all types of radiations except fast neutrons. This suggests the possibility of making a magnetic fast-neutron dosimeter as discussed in the box on page 77.

Nature of Damage

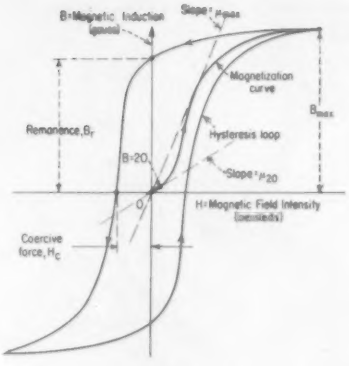
The important mechanisms for explaining radiation damage in metals are vacancies, interstitials, thermal spikes, and displacements (*1–4*). Thus one can expect nuclear displacements to produce the following macroscopic effects:

First, if the solid is previously in equilibrium, that state may be dis-

* PRESENT ADDRESS: Emerson Research Laboratories, Silver Spring, Md.

Magnetic Terms

Magnetic terms used here are defined in terms of the magnetization curve and hysteresis loop shown in this figure. Several of them are indicated there: B_{max}; B_r; H_c; initial permeability taken arbitrarily at 20 gauss, μ_{20}; μ_{max}.



Others are as follows:

Permeability $\mu = B/H$. **It is the slope of a line from the origin to any point on the curve, rather than the tangent to the curve.**

Loop rectangularity $= B_r/B_{max}$

Magnetic susceptibility

$$K = (\mu - 1)/4\pi = (B - H)/4\pi H$$

Core-loss factor $= R/\mu Lf$

$$= aB + ef + c$$

a = hysteresis-loss coefficient

e = eddy-current loss coefficient

c = residual-loss coefficient

f = frequency

B = peak core induction

turbed. Thus a nonequilibrium number of vacancies and interstitials will appear; ordered alloys will become disordered, and so on. If the temperature is high enough, the damage disappears by annealing, but if the temperature is low, these effects may not be annealed and permanent damage results.

Second, the material may not be previously in equilibrium but maintained in disequilibrium by its low temperature. An example is a quenched, disordered alloy that would be ordered if slowly cooled. Then the irradiation may actually make the material approach equilibrium.

Since the magnetic properties of ferromagnetic materials are sensitive to changes in atomic lattice structure, one expects neutron irradiation to affect these properties.

Order-disorder. Theory and experiment indicate that displacement effects due to neutron irradiation will be observed in terms of physical property changes particularly in order-disorder alloys. According to Bozorth (*5*), 5-79 Molybdenum Permalloy, when heat treated for its optimum magnetic properties, is in a critically ordered state. The marked changes we observe in its ferromagnetic properties indicate that the degree of ordering changes significantly.

16 Alfenol is also an order-disorder alloy. It exhibits its optimum magnetic properties in a disordered state (*6*). An ordered sample heat treated for *poor* magnetic properties—was irradiated to determine whether it could be improved through disordering by neutron irradiation. The results were positive—magnetic properties were improved, though not optimized.

Previous Work

Nothing has been published on the subject of neutron-irradiation effects on magnetic properties of materials for itself, but there are some partial references to it. Aronin studied radiation effects on order-disorder in nickel-manganese alloys (*7*). He reports that the intrinsic induction of ordered nickel-manganese alloys (16.5–31.9 atomic per cent Mn) shows decreases up to 80% when they are irradiated to $\sim 10^{20}$ n/cm². For thermally disordered alloys in the 16.5–22%-manganese range, irradiation raises the intrinsic induction appreciably. Above 23% manganese, the effect was reversed and the weak magnetic behavior of alloys in this region was further decreased by irradiation.

Dienes in reviewing radiation effects in solids (*3*) reports: "Recently Williams and Nesbitt observed a decrease in the saturation magnetic moment of ordered $MnNi_3$ upon irradiation in the Brookhaven pile. This change is presumably attributable to disordering of the sample."

Leeser in discussing the effects of nuclear radiation on engineering materials reports increases up to 700% in the magnetic susceptibility of some austenitic stainless steels (*8*). However, these steels are only feebly magnetic before irradiation, and even though the fractional increases are large, the total magnetism attained is still relatively insignificant.

A 1948 report on the effects of fission-produced radiation on electronic equipment states that some power, output and input transformers irradiated for 100 hr at 10^{11} n/cm²/sec showed no change in output voltage for constant input voltage (*9*).

Experimental Procedure

Our measurements were performed on seven toroidal cores especially made with radiation-resistant insulators and mountings. These were irradiated in hole W-14 of the Brookhaven reactor. After irradiation the cores were returned to our laboratories. Magnetic properties were measured before, during, and after irradiation.

Test assembly. The assembly shown in Figs. 1 and 2 permitted remote in-pile measurements as well as post-

TABLE 2—Percentage Change in D-C Magnetic Properties*

Material	*Initial permeability*†	*Maximum permeability*	*Coercive force*	*Remanence*	*Saturation*‡ *induction*	*Loop rectangularity*
3.5% silicon iron	8	−1	5.7	0.8	0	0.8
Orthonol	−31	15	−28	−24	−4	−21
5-79 Molybdenum Permalloy	−93	−93	815	−38	−3.2	−36
2 Vanadium Permendur	2.7	1.7	−2	−0.6	−0.7	0
16 Alfenol	34	15	−8	7.5	−5	13
Nickel ferrite	1.2	1.4	−4.6	−4	−1.7	−2.4
2-81 Molybdenum Permalloy	−6.8	−3.7			0.2	

* Irradiation to 2.74×10^{18} n/cm².
† μ at $B = 20$ gauss. ‡ B for $H = 30$ oersteds.

irradiation measurements when the samples were radioactive. Since organic materials commonly used in toroidal core boxes, magnet-wire insulation, and interlaminar insulating spacers are known to deteriorate appreciably at the neutron flux level under consideration, it was necessary to use inorganic substitutes. Core boxes were made of anodized 2S aluminum instead of Bakelite; interlaminar insulators were punched from 2-mil sheet mica instead of paper; and glass-covered magnet wire (Anaconda Type DX, Class H, Silotex) was used instead of Formvar-insulated wire.

Figure 1 shows successive stages in assembling a typical core used in the tests. This assembly solves a space problem imposed by cavity-size limitation in the standard lead shipping container required for returning the radioactive test assembly to the Naval Ordnance Laboratory.

Irradiation. Seven cores mounted in the core holder were irradiated for 493 hr. The flux was 1.8×10^{12} total neutrons/cm²/sec with a cadmium ratio of 1:25; that is, 1/25 of the total neutrons had energies greater than 1 ev. The integrated neutron flux to which specimens were exposed was 2.63×10^{18} thermal ($E < 1$ ev) n/cm² and 0.11×10^{18} fast ($E > 1$ ev) n/cm². The gamma flux was $\sim 4 \times 10^{11}$ photons/cm²/sec with a photon energy of ~1–2 Mev.

Temperature in the hole varied slowly from as low as 40° C to as high as 70° C, but most of the time the temperature remained in the range 55°–65° C. To eliminate temperature as a variable, preirradiation measurements were made at both hole and room temperatures. There was no appreciable difference between the two sets of data. This result agrees with previously reported information on temperature effects obtained at the Naval Ordnance Laboratory (*10*).

Absence of gamma heating in the samples is indicated by constancy of saturation induction during irradiation. Magnetic saturation is temperature sensitive, decreasing with increasing temperature.

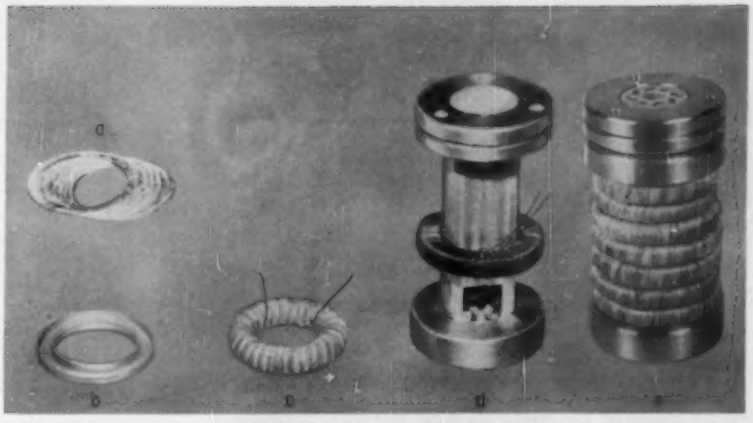


FIG. 1. (Above) Assembly of cores for irradiation. Stack of laminations (a) is placed in aluminum core box (b), wound with glass-insulated wire and glass tape (c). Finished core is mounted on core holder (d), which holds seven cores (e)

FIG. 2. (Left) Shielding container holds radioactive cores and holder after irradiation. Octal plugs in top and bottom provide cable connections

Magnetic measurements. The following magnetic properties were measured on all cores before, during, and after irradiation: d-c magnetization curves; initial permeability, μ_{20} (at B = 20 gauss); maximum permeability, μ_{max}; residual flux density, B_r; coercive force, H_c; maximum induction, B_m (at H = 30 oersteds); and a-c hysteresis loops and magnetization curves at both 60 and 400 cps. Loss measurements were made on the nickel-ferrite and 2-81 Molybdenum Permalloy (powder)

TABLE 3—Percentage Change in A-C Magnetic Properties*

Core material	*Flux density*			*Flux density*			*Loop rectangularity* (B_r/B_p)			*Coercive force*	
	H_p†	*60 cps*	*400 cps*	H_p†	*60 cps*	*400 cps*	H_p†	*60 cps*	*400 cps*	*60 cps*	*400 cps*
3.5% silicon iron	0.1	1	0.5	1	−2.5	−8	7	1.5	1.5	9	7
Orthonol	0.1	−36	−41	1	−17	−21	2	−17	−17	44	85
5-79 Molybdenum Permalloy	0.01	−92	−84	0.1	−76	−81	4	−46	−37	1,000	780
2 V Permendur	1.0	5	2.5	4	−1.5	−15	20	−6	−2.5	5	10
16 Alfenol	0.1	−4	−5	1	−1.0	−1.5	5	−1.5	1	8	4
Nickel ferrite	4.0	−2.5	23	10	−3.0	−3	20	−0.5	8	5	3.5
2-81 Molybdenum Permalloy	1.0	−7	−8	4	−7	−6	20				

* Irradiation to 2.74×10^{18} n/cm².
† H_p = a-c field intensity amplitude (oersteds) at which the corresponding properties were measured.

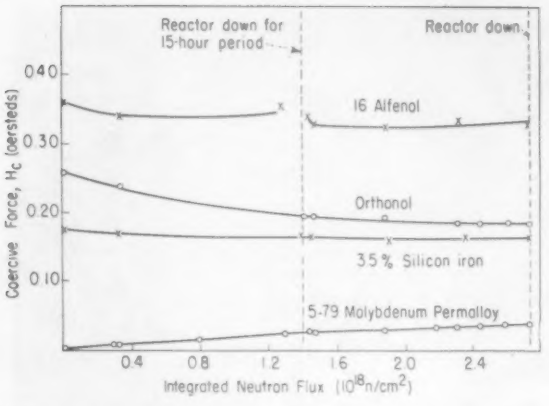


FIG. 3. Tests of d-c properties show that 5-79 Molybdenum Permalloy and Orthonol suffer greatest changes, 16 Alfenol, 3.5% silicon iron and 2 Vanadium Permendur the smallest. Graph shows effect of reactor irradiation on coercive force in four of these five materials

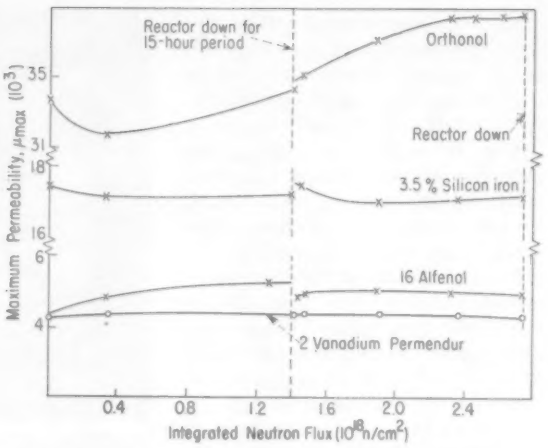


FIG. 4. Orthonol is radiation sensitive as indicated by increase in maximum permeability; 3.5% silicon iron, 16 Alfenol, and 2 Vanadium Permendur show small changes in this property

cores before and after irradiation. The magnetostrictive properties of the 16 Alfenol, 2 Vanadium Permendur and nickel ferrite were measured before and after irradiation.

D-c measurements were made with a standard fluxmeter circuit (*11*). A-c hysteresis loops were displayed on an oscilloscope using an electronic integrator in a conventional circuit (*12*). For a-c magnetization curves the peak field intensity H_p was measured by means of a peak-to-peak voltmeter across a metering resistance (*13*); the peak induction B_p was measured by means of a rectified, average-reading, vacuum-tube voltmeter (*14*).

The core-loss factor was measured as a function of both frequency and flux density. From this information, obtained with a Maxwell bridge, core-loss coefficients were obtained according to the method of Legg (*15*).

The magnetostrictive property measured on three of the cores is the electromechanical-coupling coefficient. This is considered to be the most important single parameter in the evaluation of a magnetostrictive material for transducer use (*16*, *17*).

Results

Radiation effects on permeability are summarized in Tables 2 and 3. Effects on magnetostriction and core-loss factors are presented in Table 4. Figures 3 and 4 illustrate the effects of increasing amounts of irradiation on some of the d-c properties measured during irradiation.

5-79 Molybdenum Permalloy and Orthonol show the most significant changes; 3.5% silicon iron, 16 Alfenol, and 2 Vanadium Permendur, the smallest. Between these two extreme groups lie nickel-ferrite and powdered 2-81 Molybdenum Permalloy, which show small changes in permeability but substantial changes in core-loss characteristics in the frequency range of 10–50 kcps. None of the three cores tested for magnetostriction changes showed appreciable effect.

Permanency of the effects is shown by constancy of peak induction for several materials as a function of time after the end of the irradiation period. Additional measurements of d-c and a-c properties at later dates continue to indicate that the changes in properties induced by the irradiation are permanent.

Figure 5 shows how the maximum permeability of 5-79 Molybdenum Permalloy deteriorates in a reactor environment. There is a drastic drop early in the period, and by the end of the irradiation the maximum permeability has dropped 93%. As indicated in Tables 2 and 3, the other properties were similarly degraded.

The effects of increasing amounts of irradiation on the d-c magnetization

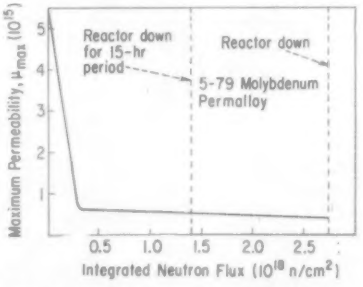


FIG. 5. Sudden drop of maximum permeability of 5-79 Molybdenum Permalloy shows that it may be unsuitable for magnetic devices that are to operate in radiation environments

Magnetic Effects for Fast-Neutron Dosimetry

The variation of magnetic properties of 5-79 Molybdenum Permalloy with integrated neutron flux suggests the potential use of this material for fast-neutron dosimetry (*19*, *20*). This is shown, for instance, for maximum permeability in Fig. 5.

Fast-neutron dose is indicated free of background from slow-neutron or gamma dose. Theory states that gamma photons produce only ionization effects, and slow neutrons produce impurity atoms only in a negligible number. A 5-79 Molybdenum Permalloy core was irradiated with gammas alone (1.4×10^{15} photons/cm^2; 1.3 Mev average energy), and no change in magnetic properties was observed.

The data imply the possibility of building a fast-neutron dosimeter using the radiation effect on the magnetic properties of 5-79 Molybdenum Permalloy. This possibility should be investigated further.

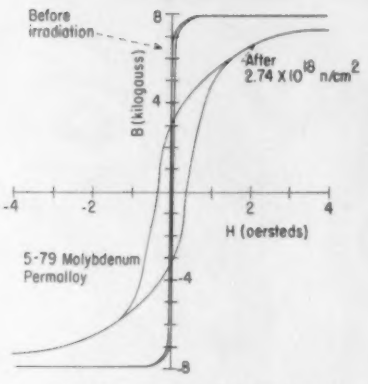


FIG. 6. Hysteresis loop of 5-79 Molybdenum Permalloy shows this change with extensive irradiation

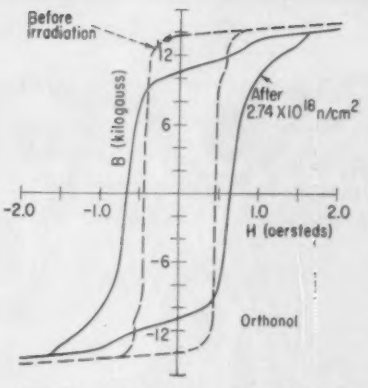


FIG. 7. Orthonol's d-c magnetization curve changes like this with irradiation in reactor fields

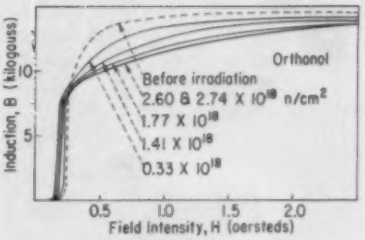


FIG. 8. Change in Orthonol's 60-cps hysteresis loop with neutron exposure

curve include a saturation effect. Figure 6, which shows the effects of the total exposure on the 60-cps hysteresis loop, further emphasizes the drastic degradation in the properties of this material. Any device depending on the optimal properties of 5-79 Molybdenum Permalloy would surely fail after exposure to this irradiation.

Orthonol also shows important changes in magnetic properties. D-c magnetization curves at increasing doses are shown in Fig. 8. The effect on the 60-cps hysteresis is shown in Fig. 7. Decrease in rectangularity, loop distortion and increase in a-c coercive force due to irradiation present a problem in the design of magnetic amplifiers.

Further Experimentation

These results suggest several further experiments that will be useful and informative. We already have completed a second experiment in which ten additional soft magnetic materials have been studied (*21*). Additional work has been reported by others (*22*). Further research with permanent magnets is in progress.

On both 5-79 Molybdenum Permalloy and 16 Alfenol diffraction and resistivity measurements should be made. This would permit correlation between changes in the degree of order produced by the radiation with changes in magnetic properties and resistivity. Reheat treatment of an irradiated 4-79 Molybdenum Permalloy core (⅛-mil tape) has been carried out (*21*). This reannealing restored the preirradiation magnetic properties of this core indicating that thermal-neutron effects—transmutations—are negligible, at least for this core.

* * *

The authors wish to thank the following persons for their contributions to this paper: John J. Floyd, Paul Colamann, Forrest P. Reeve, and the personnel of the Reactor Department at the Brookhaven National Laboratory, and C. M. Davis, S. F. Ferebee and Daniel Polansky of the U. S. Naval Ordnance Laboratory.

TABLE 4—Effect on Magnetostriction and Loss Characteristics*

Core material	K_{eff}† Before	K_{eff}† After	Total loss factor‡ $(R/\mu Lf \times 10^6)$ Before	Total loss factor‡ $(R/\mu Lf \times 10^6)$ After	Hysteresis loss coefficient $(a \times 10^6)$ Before	Hysteresis loss coefficient $(a \times 10^6)$ After	Eddy-current loss coefficient $(e \times 10^6)$ Before	Eddy-current loss coefficient $(e \times 10^6)$ After	Residual loss coefficient $(c \times 10^6)$ Before	Residual loss coefficient $(c \times 10^6)$ After
2 Vanadium Permendur	0.33	0.32								
16 Alfenol	0.19	0.20								
Nickel ferrite	0.15	0.14	8,800	12,900	450	400	40	175	6,500	3,900
2-81 Molybdenum Permalloy			500	970	1.5	1	18	38	8	

* Irradiation to 2.74×10^{18} n/cm².

† K_{eff} = effective electromechanical coupling coefficient (figure of merit for magnetostriction transducer material).

‡ For nickel ferrite $R/\mu Lf$ was measured at an induction of 1 gauss and frequency of 50 kcps. For 2-81 Molybdenum Permalloy $R/\mu Lf$ was measured at a flux density of 21 gauss and frequency o 25 kcps.

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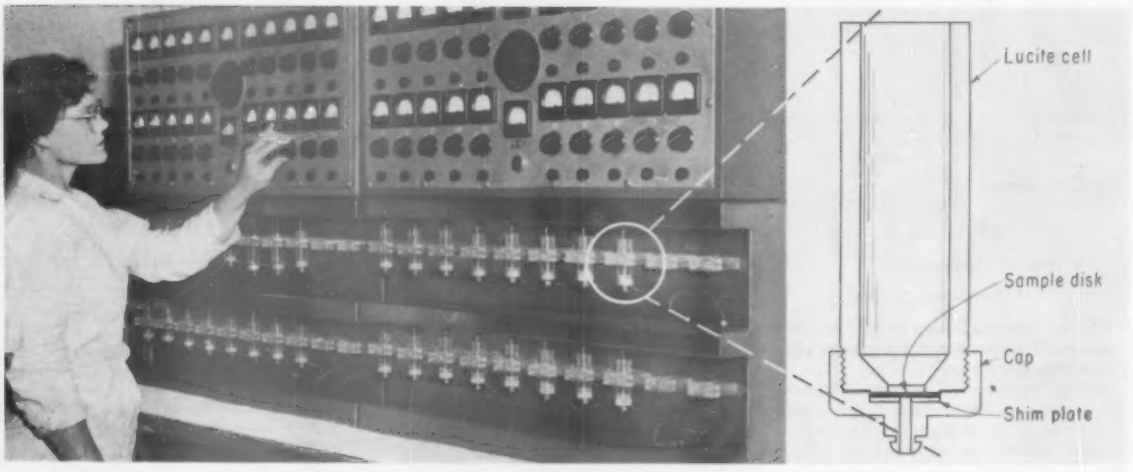


FIG. 1. Twenty-sample apparatus for electrodepositing plutonium on stainless-steel disks (at right is sketch of Lucite electrodeposition cell)

Nuclear-Track Technique for Low-Level Pu in Urine

By L. C. SCHWENDIMAN and J. W. HEALY
Hanford Atomic Products Operation, General Electric Co., Richland, Washington

Because of the low maximum-permissible body burden of plutonium, i.e., 0.04 μc or 0.6 μg (*1*), and the very low excretion rate, sensitive methods are required to detect it in urine.

For a maximum-permissible body burden, only 6 dpm (4.2×10^{-5} μg/day) will be excreted in the urine 100 days after exposure (*2*). For incipient chronic intake that eventually builds up to a maximum permissible body burden, even smaller quantities of plutonium are excreted per day because of the nearly complete immobilization of plutonium. Thus, a urine analysis should be capable of measuring much less than 1 dpm.

A nuclear-track-emulsion technique has been developed that is adequately sensitive and reproducible. The plutonium, after separation from the urine sample, is electrodeposited on a metal disk. The disk is held against a nuclear-track emulsion for 168 hr. After emulsion development, tracks are counted under a microscope. The detection limit of less than 0.05 dpm currently achieved on a routine basis is low enough to permit early recognition of low-level plutonium deposition.

The nuclear-emulsion technique is used exclusively at Hanford for routine bioassay. We have determined that a sampling frequency of four times a year is adequate for those workers who have greatest exposure potential. Other workers are sampled once or twice a year, depending upon their location.

The particular advantage of this method is that there is virtually no limit to its ultimate sensitivity. By a combination of reducing source size and increasing the exposure time, almost any desired sensitivity should be obtained. Experiments have shown that electrodeposition on 1-mm-dia areas is feasible. Another advantage is the complete freedom from the unpredictable behavior of low-background electronic counters and their higher costs.

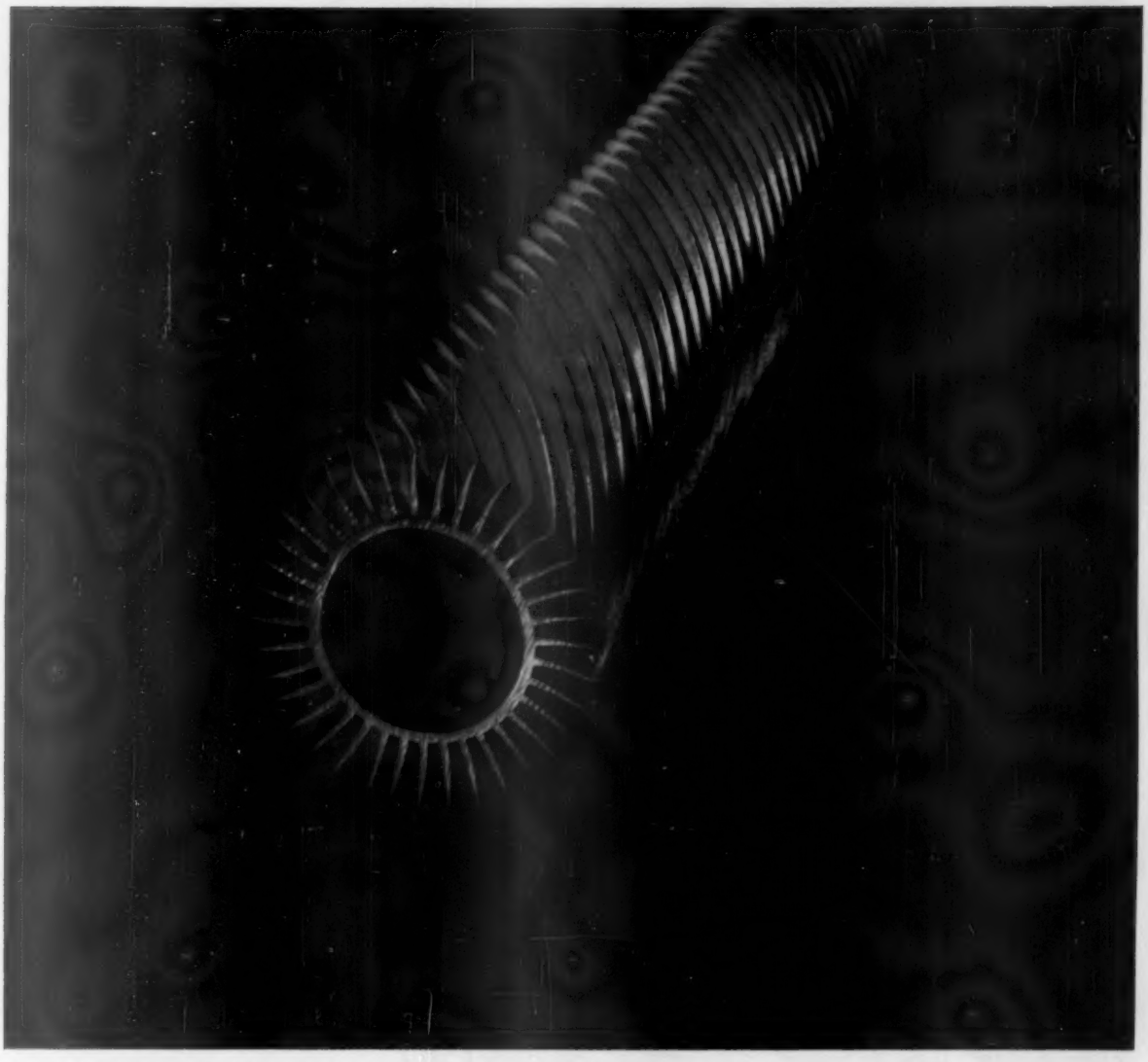
The routine procedure previously used at Hanford required evaporating the urine sample to dryness, muffling and dissolving remaining salts. Any plutonium present was then coprecipitated with lanthanum as the fluoride. After solution of the lanthanum precipitate, thenoyltrifluoroacetone (TTA) was used to chelate the plutonium now in the +4 oxidation state. The plutonium was subsequently released from the organic phase to the aqueous phase with 8*N* HNO_3, which was evaporated to dryness in a $1\frac{1}{2}$-in. counting dish. Samples were measured with low-background alpha counters. The air chambers used were sensitive to noise and other minor disturbances, and much time was expended in maintaining low backgrounds. A measurement time of up to 2 hr was needed to give a detection limit of about 0.5 dpm per sample.

Continued on page 80

Emergency Cases of Pu in Urine

Although the nuclear-track technique described in the article is suitable for routine detection of low-level Pu ingestion, the week-long emulsion exposure is too long for incidents suspected to be more dangerous.

In cases where plutonium is known or suspected to have been introduced into the body, immediate sampling is instituted. The plutonium will appear in the urine in much higher concentrations because of the short delay between exposure and sample collection. Thus, short-cut, less sensitive detection methods can be used to obtain results within a few hours. Electronic alpha counting after chemical separation of the plutonium is generally adequate.



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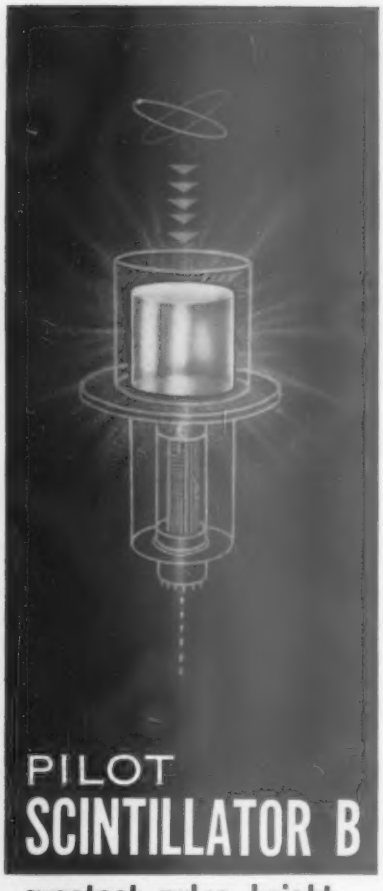

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Electrodeposition

An electrodeposition procedure was developed in which plutonium was first oxidized in a basic medium, then electrodeposited on a 7-mm diameter area in the center of a ½-in.-dia stainless-steel disk (*3*). In 1–2*N* KOH and in the presence of sodium hypochlorite, nearly quantitative recovery of 10^{-6} μc of plutonium was achieved.

The urine sample preparation, lanthanum fluoride and thenoyltrifluoroacetone method for prior separation of plutonium from urine was retained. Hydrochloric acid was substituted for 8*N* HNO_3 in the extraction when it was found that nitrate ion caused low electrodeposition yields.

A Lucite electrodeposition cell and multiposition equipment (Fig. 1) permit simultaneous analysis of as many as twenty samples. Urine samples "spiked" with a known quantity of plutonium and blank samples are processed with each group of actual samples to provide data on process control.

Nuclear-Track Detection

The nuclear-track emulsion chosen was Kodak NTA emulsion 25 μ thick on 1 × 3-in. microslides.

As received, the emulsion contains latent track images from alpha-emitting impurities. To provide maximum sensitivity, these background tracks were effectively eradicated before development by exposing the emulsion at room temperature to saturated vapor from 0.3% hydrogen peroxide. Desiccation for 3–4 hr restored the original film sensitivity. A reduction of background to less than 10% of the original track density was thus easily accomplished. Backgrounds, usually 0.002–0.004 dpm/cm², are negligible.

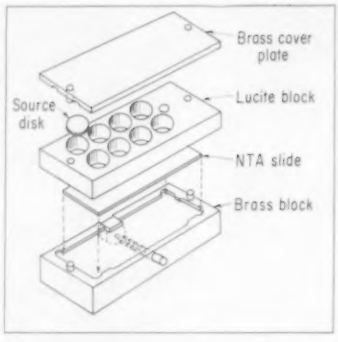


FIG. 2. Radioautographic "camera." NTA slide is inserted emulsion side up in brass block. Thumb clamp draws slide against three edge-index bosses corresponding to edge contact points of microscope stage. Lucite block is placed over slide, indexing to dowels in base block. Disks are placed in holes, plated side against emulsion. Cover plate is positioned. Printed forms identify disks

A radioautographic "camera" (Fig. 2) was constructed to support the disks against the emulsion. The emulsion is exposed to the disks at 5° C, generally for 168 hr.

Optimum developing time, without agitation, is 6 min in D-19 developer at 68° ± 2° F. Fixing requires 45 min with agitation, and washing, 1 hr.

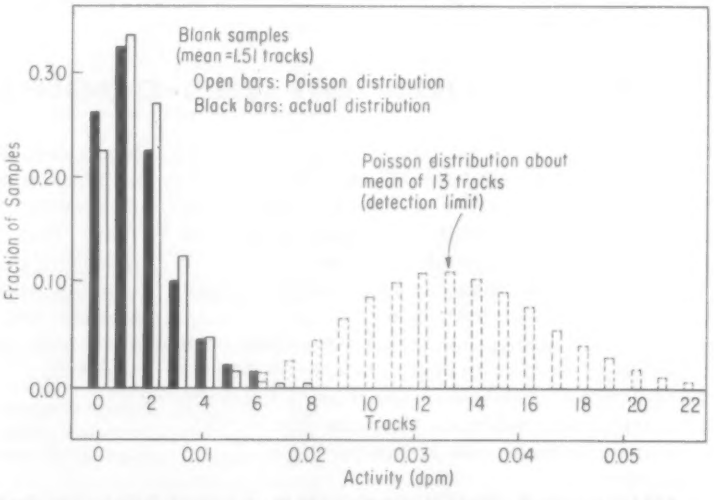


FIG. 3. At left, frequency distribution of 545 blank urine samples is compared to Poisson distribution. At right, Poisson distribution for detection limit that would give positive result above background distribution in 99% of samples analyzed

Slides are dried in a dust-free atmosphere. The slides are handled with as little exposure to safelight (Wratten Series OA) as possible to keep the single-grain background to a minimum.

The latent image of a bona-fide track in an emulsion will be destroyed over a period of time by high humidity and heat. However, if the exposed emulsion is held at 5° C, fading is imperceptible 8 weeks after exposure.

The microscopic count of tracks is made with dark-field illumination and a 43× objective and 10× eyepiece to give a total magnification of 430. Immersion oil is used between the condenser lens and the slide.

A scanning system of counting is employed. A rectangular reticule in the eyepiece delineates a 0.10×0.20-mm area of the emulsion. From the coordinates of the area to be examined, the lateral limits of the scan (4 mm long) are determined. A stop is positioned on the right-left traverse bar of the mechanical stage. This stop limits the motion of the stage to the length of the scan. A click-stop attachment to the forward-back motion knob permits the stage to be moved in ½-mm increments perpendicular to the lateral motion. These devices permit several traverses to be made on each exposed area, the total area scanned in the standard procedure is about 4 mm². The number of tracks per unit area is thus determined and a conversion to dpm made using exposure time, exposure area and film efficiency.

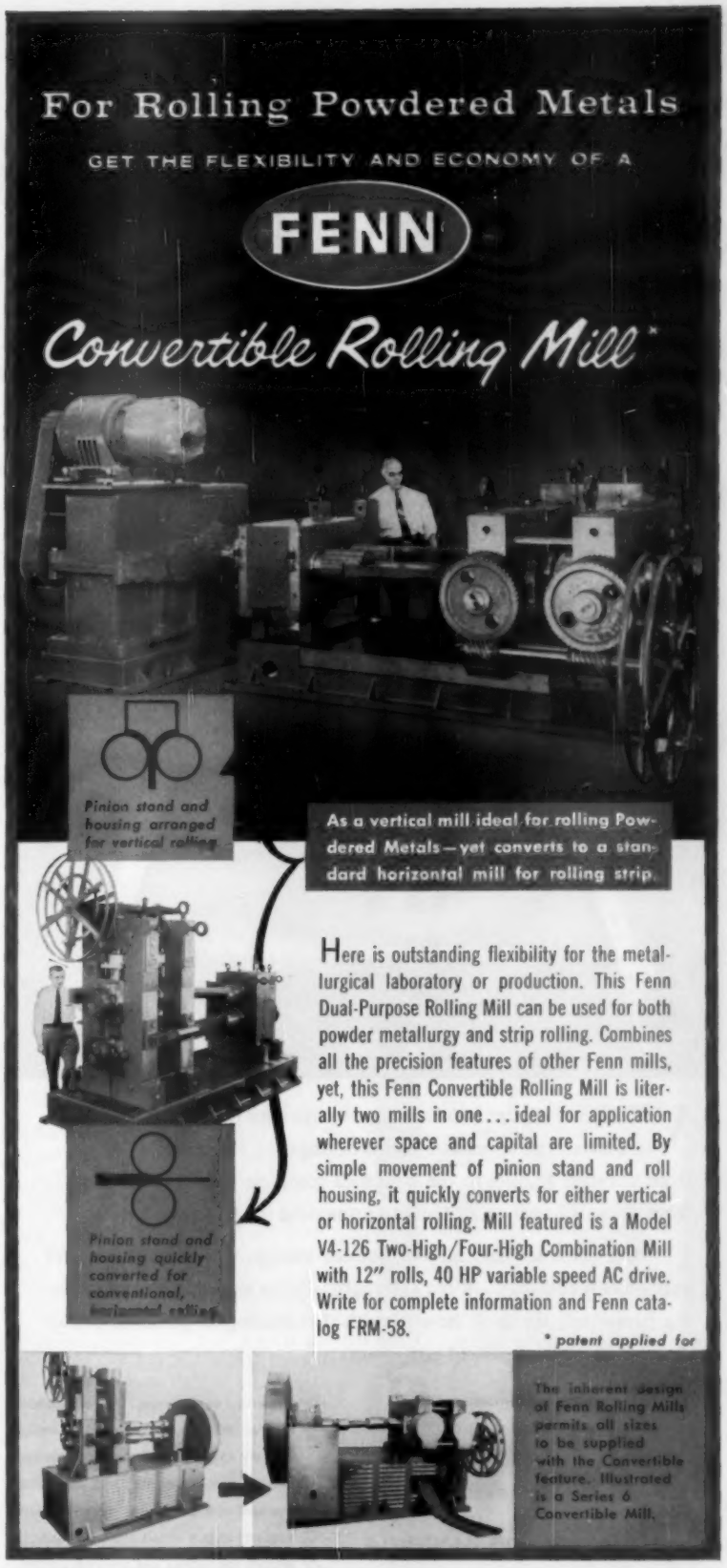
The film efficiency is routinely checked with a standard source.

Results

The frequency distribution of the number of tracks found in 3.8 mm² of emulsion for 545 blank urine samples is shown in Fig. 3.

Although it appears that the Poisson function fits the data reasonably well, the chi-square test shows the fit to be rather poor. More samples with zero tracks and with five or more tracks were recorded than predicted by the Poisson relation. The data fit well a negative binomial distribution that takes into account a lack of randomness, e.g., the degree to which the microscopist may have been favoring reading zero tracks when there were one or perhaps two present, or for there being a few contaminated blank samples. In either distribution equation, 99% of the samples showed five tracks or fewer.

It is assumed for purposes of defining a detection limit that samples contain-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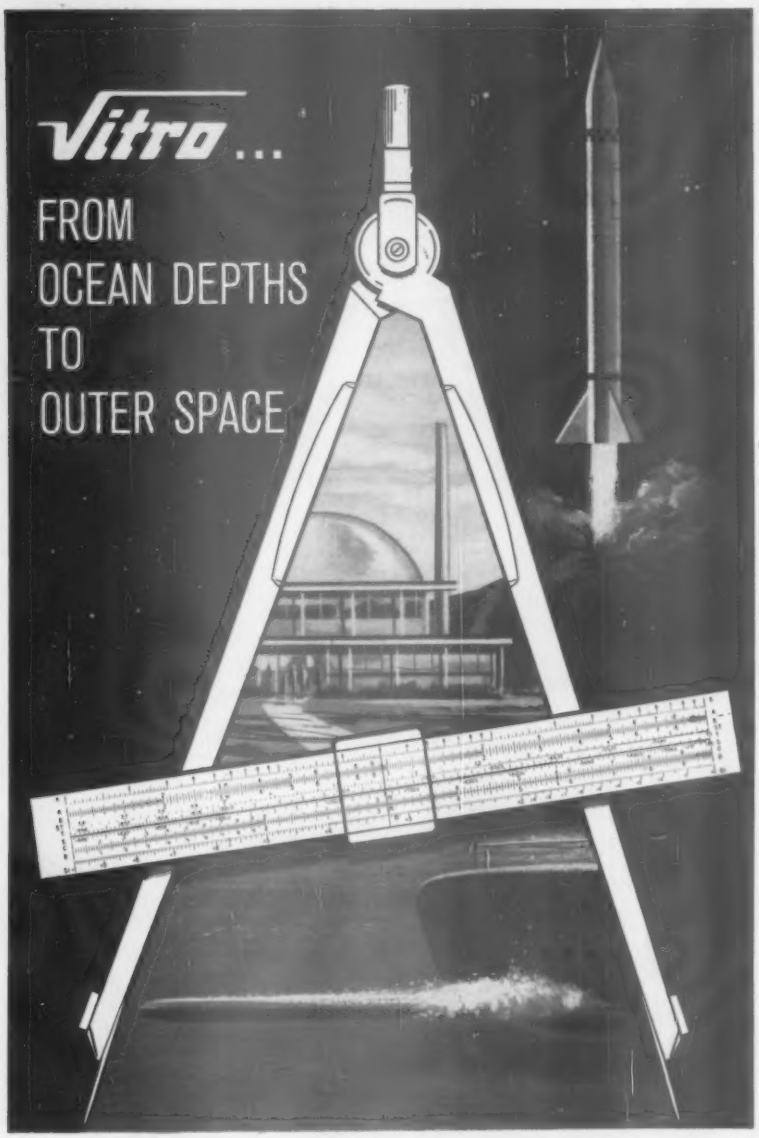

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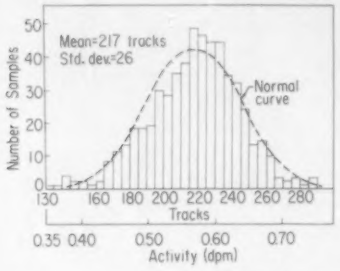

FIG. 4. Frequency distribution of 553 samples spiked with 0.57 dpm plutonium

ing a significant quantity of plutonium will be distributed to conform to the Poisson function. The detection limit is then defined as that quantity which, if actually present, would give a positive result above the background distribution in 99% of the samples analyzed. These data indicate that 0.033 dpm actually present in the sample would result in a measured dpm greater than the 99% upper limit in the background distribution 99% of the time. It should be noted that values greater than the 99% upper limit of the background distribution but lower than the 0.033 dpm indicate positive values and should be treated as such.

Figure 4 gives the distribution of 553 samples "spiked" with 0.57 dpm of plutonium as determined with a PC-2A proportional counter. These samples were analyzed concurrently with the regular bioassay urine samples. The standard deviation is 12%. If only random variations from reading the tracks were present, the standard deviation should be 7%. The remaining variation results from all other random errors in the process. The long-time average of the over-all process yield is 89%, assuming a 50% emulsion geometry. Emulsion geometry will, in general, be slightly less than 50%, principally because tracks perpendicular to the emulsion plane are not recorded.

* * *

This article is based on work performed for the U. S. Atomic Energy Commission under contract W-31-109-Eng-52.

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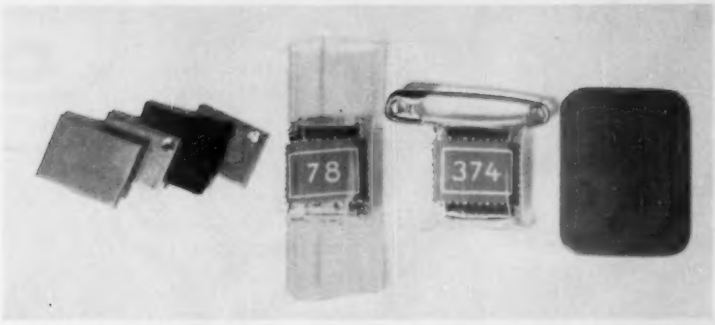

FIG. 1. Film badge for monitoring X- and γ-rays. Left to right: components of badge (films and perforated filters); components wrapped in aluminum foil, numbered and inserted in 0.3-mm polyvinylchloride tube; completed badge; conventional-size film (3 × 4 cm)

New Film Badge Enables Cheaper X-Ray Monitoring

By L. H. M. van STEKELENBURG
Department of Medical Physics
National Health Research Council T. N. O.
Arnhem, Netherlands

Beta- and gamma-ray monitoring by the photographic method is precise enough to guarantee accuracies of ±10%. Although X-rays can be monitored with similar accuracy, the process is time-consuming and more costly because of energy dependence and the need for calibration.

We have developed a universal film badge (Fig. 1) that indicates X-ray dose with a single reading. The same film badge can be used for X- and γ-rays.

The badge contains two differential films. One film is shielded on both sides by 2-mm tin, while the other is directly exposed. If appropriate films are used, there is a linear combination of their densities that is practically constant for equal radiation doses of

Half-Value Layers for Filtered Radiation

Energy (*kv*)	*Filter* (*mm*) *Sn*	*Cu*	*Al*	*Approximate half-value layer* (*mm Cu*)*
X-rays				
50				0.04
50			0.5	0.05
70			1.0	0.08
90			2.0	0.15
110			4.0	0.25
130		0.25	1.0	0.55
150		0.50	1.0	0.85
180		1.00	1.0	1.6
210	0.4	0.25	1.0	2.4
250	0.6	0.25	1.0	3.2
250	Same as 1-mm Pb			5.0
Gamma rays				
Cesium-137 (0.66 Mev)				9
Cobalt-60 (1.25 Mev)				16

* All half-value layers have been expressed in mm Cu for ease of plotting.

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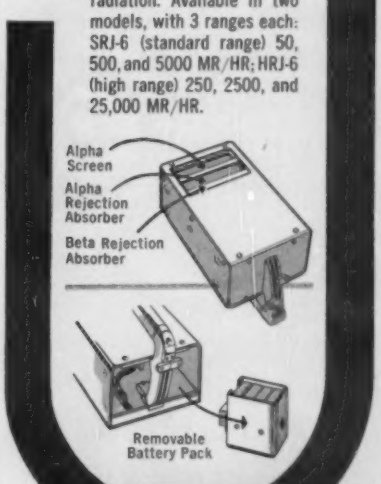

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NUCLEAR ELECTRONIC ENGINEERS

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This article starts on page 83

different spectra. Response to X- and gamma rays of energies between 0.03 and at least 1.25 Mev is linear to within 20%—thus eliminating the need for film calibration.

Radiation monitoring with films is complicated by the fact that their response to X-rays varies considerably with energy. Hence, when a film has been exposed to X-rays of a given half-value layer, reading the dose requires a comparison with one or more calibrated films. Thus, a correct dose measurement is impossible without knowing the radiation spectrum.

As one cannot expect the customers of a film-badge service to provide the necessary information, it should be collected by the film itself. For this purpose it is common practice to shield the film partially with different metal filters. As long as the incident radiation is practically monochromatic, the absorption in such a filter is a reliable measure of the radiation spectrum. In most cases only one of the filters gives accurate results because the absorption in the other ones is very small or nearly complete. The attenuation by this first filter permits an estimation of radiation spectrum to be made and the choice of the proper calibration film.

If the radiation is heterogeneous, the one-filter method is likely to fail. For example, if the film has been exposed simultaneously to 10- and 1,000-kev X-rays, both of which are rather ineffective in producing film blackening, the apparent spectrum may be that of homogeneous 100-kev X-rays to which the film is much more sensitive. As a result a wrong calibration film will be chosen, which leads to an appreciable underestimation of the dose.

To avoid this pitfall, Dresel has developed a rather laborious method that involves splitting up the dose into soft, medium and hard X-rays (*1*). Though offering an improvement in accuracy, this method does not obviate the fact that the variable response of X-ray films restricts their optimal use to limited energy ranges.

For this reason most manufacturers produce several brands of film. The more sensitive type is recommended for gamma monitoring. Unfortunately it is not always possible to restrict one's exposure to one type of radiation, or even to know the origin of one's dose.

As an expedient, filters have been used to level the response of X-ray films. Deal *et al.* obtained a constant response to gamma rays with energies exceeding 200 kev by shielding the film on both sides with 1-mm cadmium (*2*). However, the decrease of response at energies below 200 kev is enhanced by the filter. Hence such film badges can be used for monitoring gamma rays from radium and radioisotopes but not for X-ray dosimetry.

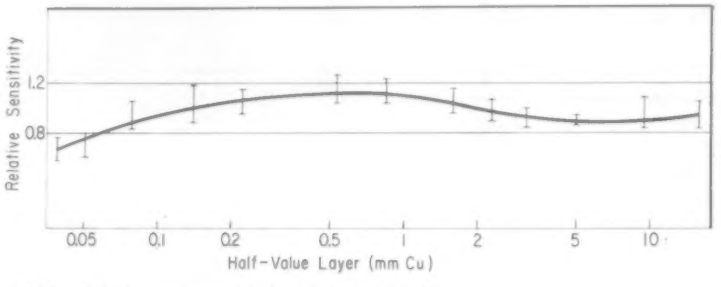

FIG. 2. Relative response of Ilford film combination

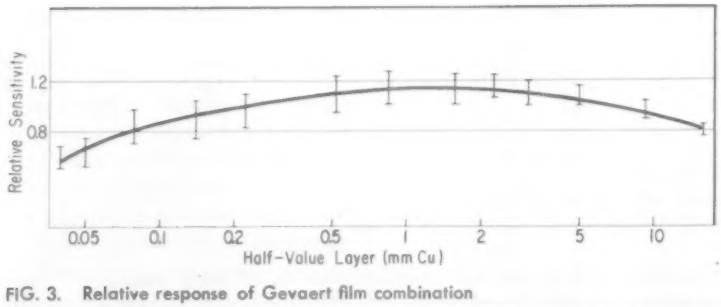

FIG. 3. Relative response of Gevaert film combination

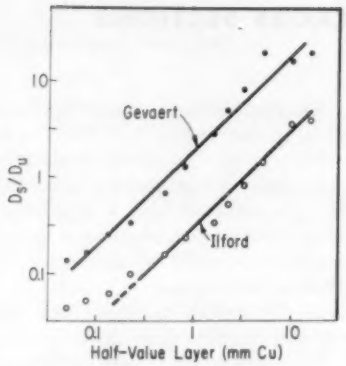

FIG. 4. Ratio of shielded and unshielded densities (D_s/D_u) vs half-value layer in copper

New Badge Design

We have extended the range of constant badge response to lower energies on the basis of the following considerations.

When the film is used without a filter, its response has a flat maximum at approximately 100 kev. Outside this region there is a gradual decrease to a negligible level. Consequently if we use one film in Deal's or a similar mounting and another film unshielded, there is a linear combination of both film densities that, the dose being kept constant, does not depend upon the radiation spectrum beyond 200 kev, and in a region around 100 kev.

Because of the opposite behavior of both films in the intermediate region, the gap can be filled satisfactorily if appropriate films and filters are chosen.

We have checked this idea with the energies listed in the table for two combinations of commercially available films: (1) Ilford PM1 between filters and Ilford PM3 unshielded, (2) Gevaert Osray between filters and Gevaert Structurix D4 unshielded. The results are given in Figs. 2–4.

The films were cut in 15 × 20-mm strips and packed in paper. The more sensitive film was between two 2-mm tin filters; the other film was on the front side of the badge. Though the shielded film was recognizable by its greater stiffness, it was convenient to mark it by a black spot in one of the corners. This was done by perforating all filters.

All X-ray exposures were made 150 cm from the X-ray target. The gamma doses were calculated using 13.5 mr/hr/mc at 1 cm for Co^{60} and 3.4 for Cs^{137}. The films are developed at 18° C in Agfa rapid X-ray developer for 2 min. *Continued on next page*

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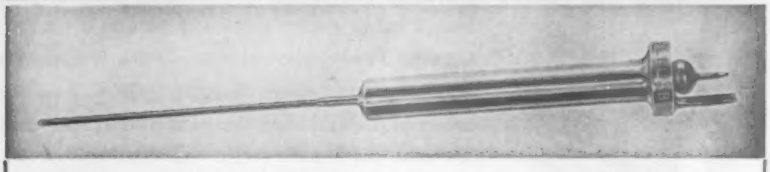

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CROSS SECTIONS

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All density measurements are made with a barrier-layer photocell and galvanometer. A direct reading of film density was obtained by providing the galvanometer with a logarithmic scale (base 3, in accordance with the sensitivity steps of the galvanometer). Thus an attenuation by a factor of 3, compared with the unexposed film, corresponds to a density of 1 in our system.

If we denote the densities of the unshielded and shielded film with D_u and D_s, respectively, the optimal response curve for Ilford films is obtained with the density combination $D = D_u + 3D_s$.

Figure 2 gives the results of six consecutive experiments. The density $D = D_u + 3D_s$ per dose unit has been plotted in arbitrary units against the half-value layer (HVL) of the radiation in copper. For HVL's greater than 0.08-mm Cu, the response varies between the limits 0.8 and 1.2. Hence the error caused by the energy dependence of the films has been reduced to a maximum of 20%.

For 0.5 r, the average value of D amounts to about 5. It is proportional to the dose to within 10% up to doses of about 1.2 r.

Similar results are obtained with Gevaert films (Fig. 3). The most favorable density combination with these films is $D = D_u + D_s$. For 0.5 r, a value of $D = 2.5$ is found.

While the response of the Ilford film combination is slightly more constant, the Gevaert films have the advantage that the sum of their densities is independent of the radiation spectrum. Hence the separate measurement of both densities is redundant.

Though not of primary interest, it may be helpful to identify the source of the dose by an estimation of the radiation spectrum. This is possible because D_s/D_u varies considerably with the radiation spectrum, as is shown in Fig. 4. As a rule of thumb, one can say that D_s/D_u is proportional to the half-value layer. As a matter of fact, this method fails if one or both densities are too small to be measured accurately. In the first case we only know which end of the spectrum we deal with; in the second case the dose is so small that we can neglect the identification of the spectrum.

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Simple, Inexpensive, Automatic Sample Changer and Recorder

By E. S. KEMPNER and F. A. BISBEE
Biophyics Department, Yale University
New Haven, Connecticut

A simple, inexpensive automatic sample changer and recorder was designed for counting radioactive samples that are on the surface of filter papers.

The samples are positioned with vaseline or vacuum grease on the circumference of a large drum, 35 in. in diameter and 4 in. thick. The drum is mounted on a horizontal axis in a table as shown in Fig. 1. The G-M tube is held vertically in a carriage that rides on the drum surface, insuring that the face of the tube is a constant distance away from the radioactive sample; this becomes critical for weak emitters such as carbon-14 and sulfur-35.

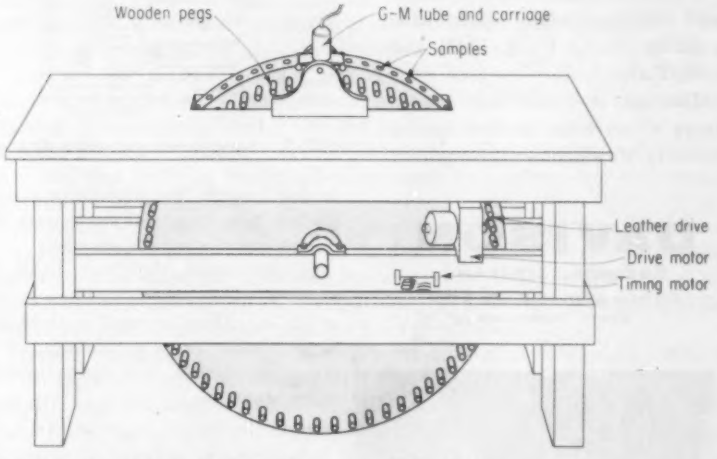

FIG. 1. Motor-driven drum provides automatic sample changer

The G-M-tube carriage is made of 1½-in-o.d. tubing on a ½-in. brass plate that shields the tube from radiation from other samples. The plate is fitted with four Lucite wheels that are in contact with the drum. Two springs that attach the brass plate to blocks of wood fixed to the table restrain the horizontal motion of the G-M tube, while allowing the carriage to ride free vertically on the drum.

A 6-rph timing motor actuates a microswitch once every 10 min. This switch controls a 3-rpm drive motor, which changes samples in 7 sec. (A microswitch arrangement on the drive motor allows it to make only one revolution each time the timing motor actuates it.) The leather arm on the drive shaft pulls successive wooden pegs that are mounted at 5-deg intervals around the perimeter of the drum. In the event of jamming between the arm and the pegs, the leather arm gives and the wheel is freed. A wiring diagram is given in Fig. 2.

The G-M tube feeds into a conventional scaler and counts continuously. The mechanical register on the scaler was removed, and the impulses from the last scaling circuit are fed directly into a 48-volt, d-c, 2,000-ohm relay. As can be seen in Fig. 2, the drive motor feeds a 7-sec

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impulse to this relay every time the sample is changed. The relay controls a 110-volt, a-c relay with an extended arm, the end of which is fitted with a ball-point pen. The pen rests on an adding-machine tape, which is pulled past the pen by rubber rollers. Sample changes appear as square pulses on the tape, while counts from the scaler are seen as single strokes.

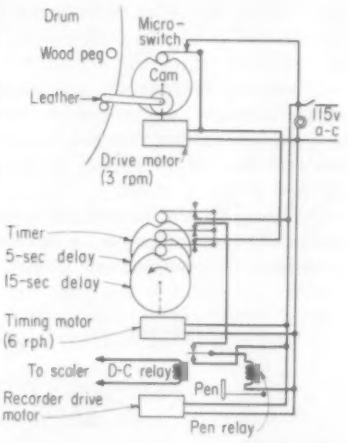

FIG. 2. Sample-changer wiring diagram

In this manner, the tape keeps a continuous time record of the counts per sample and the sample changes.

In our model, the drum holds 72 samples, which are counted in a period of 12 hr. Obvious modifications are larger drums or a continuous slow-drive mechanism for counting-strip chromatograms.

* * *

This work was aided by a grant from the U. S. Public Health Service.

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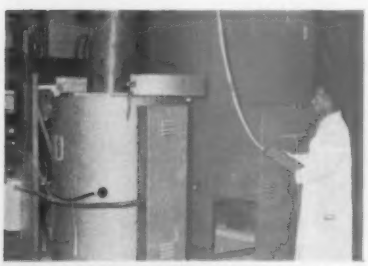

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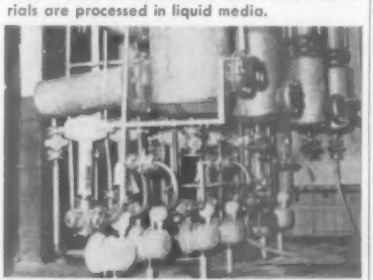

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NUCLEAR ENGINEERING NOTES

Zircaloy vs Stainless: How Designers Feel Although, as a reactor structural material, Zircaloy has favorable nuclear properties and is competitive with stainless steel on a cost basis for many reactor types, reactor designers still shy away from it. The main reasons for this are that its fabrication and performance are relatively unknown quantities.

This is the impression created by discussions in New York and Pittsburgh of a study by Manson Benedict for the Columbia-National Corp. (NU, April '58, p. 104). Participating were reactor designers and fuel fabricators.

Benedict based his study on comparative-cost calculations for using Zircaloy and stainless steel for five reactors: NPD (Canadian GE), Sodium-Graphite Reactor (Atomics International), Yankee Atomic Electric Reactor (Westinghouse), Merchant Ship Reactor (Babcock & Wilcox) and Vallecitos Boiling Water Reactor (GE).

Of particular interest were the comments of the designers of these reactors. Most of them have made similar studies. Generally their assumptions and conclusions were in close agreement with Benedict's. Thus, Zircaloy is economically feasible for permanent reactor parts and for cladding—except, in the case of cladding, for fuel enrichments above 4%.

However, the designers feel that insufficient experience has been gained on the fabrication and performance of Zircaloy. This means that considerable development costs would be entailed in any application.

Following are some of the designers' remarks.

NPD. W. B. Lewis (Atomic Energy of Canada, Ltd.) commented that because of special concern about neutron economy in natural-U reactors, "we are more ready to pay a good price for Zircaloy if it meets a high metallurgical and corrosion-resistant specification and tight dimensional tolerance."

Yankee. In its considerations, according to Robert McGeary, Westinghouse has "placed a good deal of emphasis on the fact that Zircaloy is a more reactive material than stainless steel." At the break-even price, they would choose stainless since it is a more "sure-fire" material. Also, from their experience, they feel that it would be difficult to evaluate how extensive a development program would be necessary.

Indicative of the lack of experience in working with Zircaloy, Benedict agreed with Roger Coe (Yankee Electric) that fabrication costs of Zircaloy are probably higher than for stainless. However, there appeared to be no firm idea of how much higher the cost is. In his original calculations, Benedict had assumed that fabrication costs would be the same for the two materials.

Nuclear Merchant Ship. The NMSR core is to be all stainless steel. Because of the tight schedule and fabricability considerations, said Gerald K. Rhode (B&W), any substitution of core materials is not anticipated. However, he pointed out that control-rod worth favors zirconium as fuel-rod cladding and fuel-element canning for a reactor of NMSR size and type (the NMSR element consists of 192 stainless-clad rods in an 8½-in.-square stainless can). With zirconium cladding and canning, excess reactivity is greater for a given excess mass and increases at a greater rate with increasing excess fuel mass than in the case of stainless cladding and canning. Since the excess mass held down in a zirconium core may be almost the same as the excess mass held down by a stainless core and the conversion ratios are not too different, similar reactivity lifetimes will be obtained.

Sodium-Graphite Reactor. R. C. Gerber (Atomics International) agreed for the most part with Benedict's conclusions. However, AI would use Zr cladding twice the thickness of the stainless cladding. This brings the Zr cladding break-even price to $30/lb compared with Benedict's break-even price of $57. AI is concerned about two technological problems associated with using zirconium in the sodium system: (1) grain growth of zirconium at the desired operation temperature (1,000° F) and (2) pickup of oxygen by zirconium at high temperatures and consequent embrittlement. For these reasons, operation is presently limited to 900° F. In the sodium reactor experiment at Santa Susana, equipment was added to the sodium system to keep oxide content down to ~10 ppm or less. On the other hand, stainless steel would not necessitate the temperature limitation nor the special treatment for oxides. Thus, stainless is presently favored for the Nebraska sodium graphite reactor.

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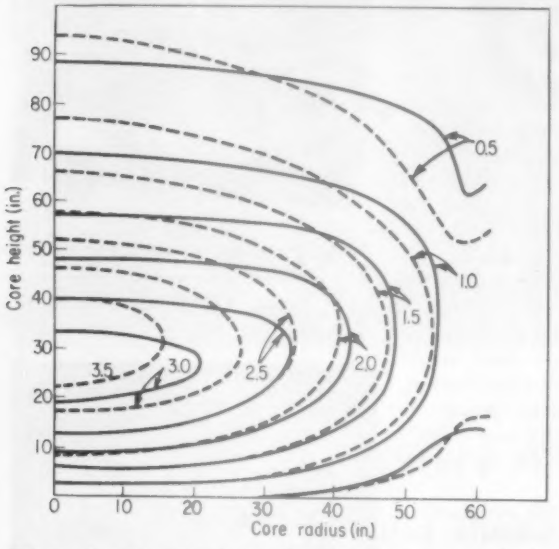

FIG. 1. Two-dimensional plot of local-to-average power density for large boiling-water reactor. Solid contour is for core with no inlet orificing; dotted contour is for core with inlet orificing

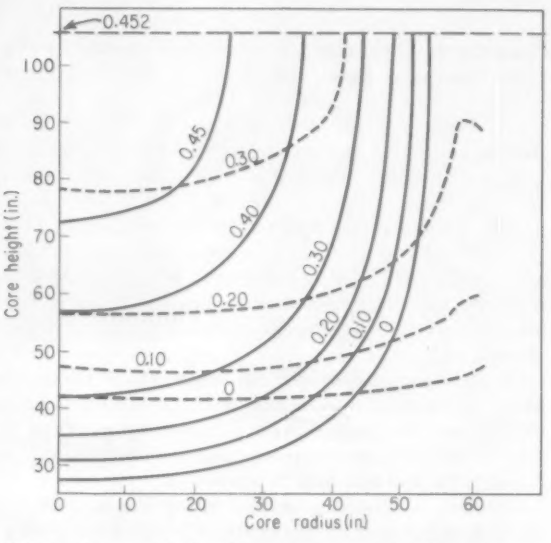

FIG. 2. Steam void fraction contours corresponding to power patterns shown in Fig. 4. Solid contour is without inlet orificing; dotted contour is with inlet orificing

Void-Induced Power Distortion in Boiling-Water Reactors

By JOHN W. WEIL
Atomic Power Equipment Dept., General Electric Co., San Jose, California

In any practical boiling-water reactor design, the insertion of bubbles in the core reduces reactivity. Consequently, if bubbles are distributed nonuniformly throughout the core, the part of the core that contains the most bubbles will have the lowest reactivity and the power peak will tend to shift away from that position. It is found that in this way steam voids in the core of a large boiling reactor can cause power-distribution distortions large enough to be of engineering significance. Because of these power distortions, the functions of engineering and nuclear design are much more tightly coupled than is the case for other reactor types. Core-heat-transfer and fluid-flow characteristics must be determined with the nuclear physics in mind, and the nuclear physics must consider the heat-transfer and fluid-flow characteristics. This is in contrast with most other reactors where the power distributions can be estimated fairly early in the design procedure and where changes in fluid-flow and heat-transfer characteristics do not affect the nuclear design.

Although the treatment of the problem as presented here was developed as a part of the design effort for the Dresden nuclear power station, the examples used and the conclusions reached (see Figs. 1 and 2) are applicable to all boiling-water reactors of the same general size that use light water and the dual-cycle principle.

Power-Distortion Conditions

Much attention, both theoretical and experimental, has been focused on the dynamic effects of steam bubbles in the core of a boiling-water reactor. As a part of most of these studies the steam bubbles have been assumed to be distributed uniformly through the reactor core. This is an adequate approximation for the experimental reactors that have run to date, but it is not adequate for large power reactors. While the dynamic situation becomes exceedingly complex without this approximation, the static situation is capable of analysis and is of major interest in the investigation of the *internal* characteristics of large boiling reactors.

To date, experimental investigations of the change in power distribution within a boiling reactor, caused by the presence of steam bubbles, have revealed only small power distortions primarily because of the comparatively small reactor core sizes involved. In a reactor with a core approximately 4 ft high, the power distribution will shift slightly when the reactor is permitted to boil, but the shift is relatively insignificant and does not materially affect the engineering characteristics of the core.

However, as the core size becomes large compared with the migration length for thermal neutrons, the actual

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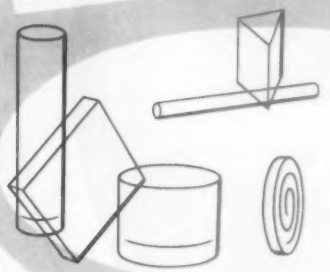

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This article starts on p. 90

core size will, in practice, be large compared to the minimum critical size for the lattice in question. Consequently, the core acts in many ways as if it were composed of a number of separate, loosely coupled nuclear systems. It follows that the power distribution can become severely distorted and that this possibility is of considerable importance to the design of a central-station power reactor core. At the same time this flexibility in power distribution offers an opportunity to the reactor designer to use these special characteristics to advantage.

The dual-cycle system may introduce further distortions in power generation. Although the dual cycle permits higher specific heat extraction from a given boiling-reactor core, the fact that subcooled water is introduced into the bottom of the core causes the initial boiling boundary to shift up to some point toward the middle of the core. Similarly, the exit void volume fraction will become much higher than in a simple boiling reactor and there will be an increased tendency for the power to shift to the lower portion of the core. Depending on the reactor design, this may or may not be desirable. The discussion here will attempt primarily to provide an understanding of the characteristics of such a redistribution of the reactor power.

Power-Distortion Analysis

To understand how to calculate the influence of the steam voids on the power pattern consider the heat-transfer sequence in a boiling-water reactor core. As water is introduced into the bottom of the core and flows upward through the cooling channels, heat is added to it as a functon of position from the bottom of the core. Normally, this function of position will depend on the radial position of the coolant flow channel in question. For the time being we assume a flat radial power distribution; that is, the composition of the steam-water mixture is uniform at each height. As energy is added to the water it is first warmed and then, after reaching the saturation point, begins to develop a volume fraction of bubbles. As the energy content is increased, the bubble volume increases. Similarly, as the energy content is increased the velocity of the steam or water will increase (see Fig. 3).

With this information and a first

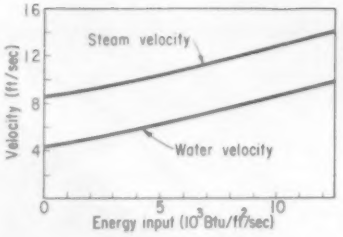

FIG. 3. Steam and water velocity in a vertical coolant channel as a function of the energy absorbed in moving up the channel (starting at the boiling boundary). A constant difference of 4 fps was assumed between the steam and water velocity (steam slip velocity)

approximation to the reactor power distribution, it is possible to integrate the power distribution up the reactor to any given height and thus determine the steam concentration at that height. The resulting distribution of steam voids in the reactor core may then be used as the basis for a calculation of the reactor neutron flux distribution corresponding to that void distribution. This will produce a second approximation to the power distribution that will normally not agree with the initial approximation. This iteration procedure can be continued until a set of self-consistent power and void distributions results.

Needless to say, this is a tedious procedure since it involves not only the usual several-group calculation of reactor flux and power for a nonuniform reactor core but also involves integration of the reactor power distribution and appropriate changes of reactor composition to match the resulting distribution. This cycle must be repeated many times even for the very simplified case discussed here. We have found it necessary to develop a series of digital computing machine programs to carry out the over-all iteration procedure with greater speed and convenience.

The situation is further complicated for a large light-water reactor in that the flux and power solutions for a given reactor composition converge very slowly when the reactor leakage is small. Consequently, fairly sophisticated numerical-analysis acceleration techniques are needed to force conversion of the power and flux iterations in a reasonable length of time.

Typical Results

Using the iterative procedure we can derive the perturbed power patterns for typical situations. Take, for in-

stance, the nonboiling power distribution in a small, low-enrichment boiling reactor, similar to those already put into operation. This is the distribution for the reactor in the hot condition just prior to the onset of boiling. Upon going to full power boiling operation our calculations show that the pattern will shift as shown in Fig. 4. There is a noticeable, but relatively unimportant, change in the power distribution. The power peak has shifted down somewhat and the peak-to-average power has increased from 1.36 to 1.42. Neither of these changes has any major design consequences.

The corresponding power distributions for an extreme case of a large, poorly designed dual-cycle reactor are quite different. (See Fig. 5.) The power distribution is depressed considerably toward the lower end of the core and the peak-to-average power has been sharply increased. Because of the dual-cycle operation, boiling does not begin until approximately halfway up the core. The void content builds up rather rapidly just above that point. For a 4-fps inlet velocity the steam exits at 12 fps and the saturated water at 8 fps.

While this model of a boiling-water reactor is already quite complicated to calculate it is, unfortunately, not adequate to permit design of large boiling reactors. Contrary to our assumption the radial power distribution is not flat and the composition of the reactor is therefore not uniform at each height. Channels toward the outer portion of the core will have a lower total power generation resulting in a different void distribution there than in the center of the core. Thus the normal approach in which radial or axial power distributions are separable breaks down and one must consider power distributions in a large boiling reactor on a true two-dimensional basis.

2-D Calculations

Let us look at two sets of two-dimensional calculations made for a reactor similar to the Dresden station. Figure 1 shows the power distribution for the case where the inlet-water velocity is constant as a function of radial position. Note again the tendency for the power distribution to shift down and also the tendency for an inherent radial flattening of the power distribution. An over-all (combined radial and axial) peak-to-average of 4.0 is observed for this case. The corresponding void distribution is shown in Fig. 2. Note the deep penetration of voids into the center of the reactor core and the fact that some of the external channels never boil at all. To correct this condition orifices were placed at the bottom of each flow channel to restrict the flow into the outer regions of the core. The orifices were sized to produce a constant exit steam quality in the case just examined. The resulting power distribution is compared with the previous one in Fig. 1. It is somewhat less flattened on the top and shows a more normal behavior. The associated void distribution in Fig. 2 shows considerable change, pointing up what can be done with orificing. It should be observed, however, that the orifices have not produced constant exit steam quality primarily because of the shift in the power distribution. Consequently, further attempts would be necessary to achieve the specified constant exit quality condition.

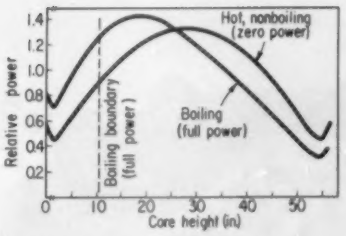

FIG. 4. Comparison of axial power distribution with and without steam voids for small boiling-water reactor

Another point of interest is that for the same total reactor power output there is less reactivity represented by voids in the orificed reactor. This is so because the deep penetration of the steam voids into the central, high-statistical-weight region of the reactor has been eliminated by redistribution of the coolant flow. This reduces neutron streaming—and, hence, leakage—and raises the k_∞ of the high statistical weight regions of the reactor. Presumably then, the void-reactivity characteristics of a given boiling reactor may be varied at the option of the reactor designer or operator to produce the most favorable design characteristics.

As discussed above, one-dimensional axial calculations are tedious and necessitate special computational tools. The two-dimensional problem is more complex by an order of magnitude. While the calculations shown were carried out by performing the neutron diffusion calculation using existing two-dimensional machine techniques and performing the power integration

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and the composition changes by hand, the amount of effort involved was prohibitive for extended design applications. It has been found necessary to produce a special, high speed, digital computer program that evaluates boiling-reactor power distributions in both

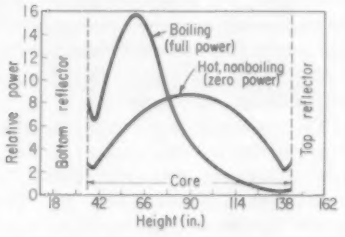

FIG. 5. Comparison of axial power distribution with and without steam voids for large boiling-water reactor

the static and quasi-static time-dependent cases. This program is just now undergoing its initial operation and will take 30–90 minutes of machine time to calculate two-dimensional boiling-reactor power distributions. With this program a large boiling reactor may be designed for maximum economic performance by tailoring the power distribution by means of orificing, control rod scheduling, or lattice and enrichment variation.

* * *

This paper represents the combined efforts of a large number of people within the Atomic Power Equipment Dept. of the General Electric Co. In particular, acknowledgements are made to P. Cabral, G. Keirns, and D. V. Steward for their extensive efforts in carrying out many of the calculations.

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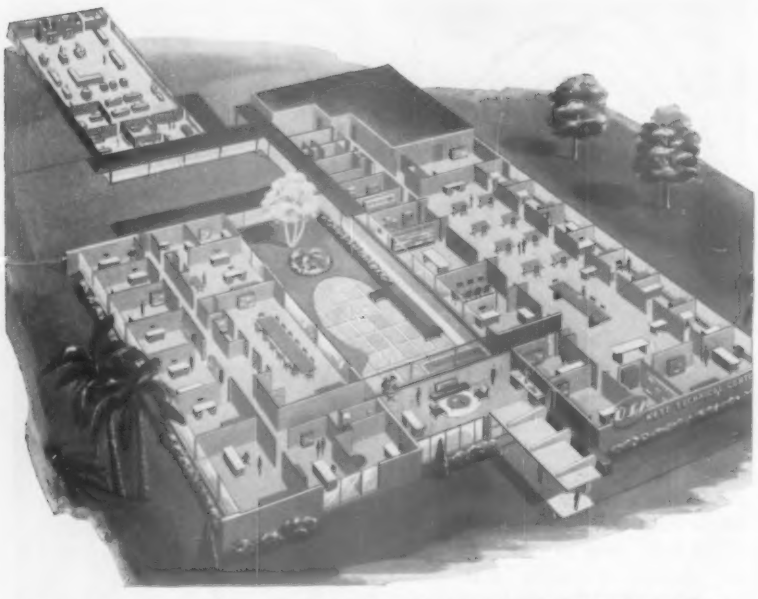

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Water-Channel Peaking Factors

By R. W. DEUTSCH
General Nuclear Engineering Corp., Dunedin, Florida

For light-water reactors loaded with metallic fuel elements, the presence of a water channel adjacent to the fuel-moderator region introduces a power peak at the channel boundary. Such peaking has considerable effect on the heat-transfer and burnout characteristics of fuel elements in the vicinity of the channel boundary. Since the local neutron flux may be considerably higher than the average flux, there is a possibility of boiling as well as a high fuel burnout.

Water channels are present in reactor designs for many reasons. In loading a reactor, it is desirable to insert the fuel in bundles or unit cells rather than as individual elements, so that large open water spaces appear between bundles. Also, if the reactor is rod controlled, water channels will appear upon the withdrawal of control rods. The effect of the channel for the two cases cited can be minimized by reducing mechanical tolerances as well as putting tails on the control rods. However, these measures add to the cost and complexity of the mechanical design. For this reason, one would like to live with water channels especially in high-performance reactors where the thermal margin may be small. Therefore, the reactor designer must be able to calculate both individual and collective channel effects.

Unfortunately, the precise mathematical solution, even for one energy group, of a complex geometry that contains corners such as a Y-shaped or cross-shaped channels surrounded by other channels involves a numerical solution or series solution of slow convergence. Such solutions, while of great value in understanding the general problem, are extremely time consuming and the physics is apt to be lost in the algebraic manipulation. As an alternative we offer here a simple prescription that provides certain design criteria to evaluate peaking of intersecting slabs in a complex geometry. For example, this prescription indicates that under some conditions, it is desirable to *increase* the number of channels or possibly *widen* some channels in order to optimize peak to average fluxes throughout the reactor core.

Deriving the Prescription

Simple one-velocity diffusion theory and physical arguments are used to treat each slab channel as a linearly independent source whose presence contributes a current at the channel interface that perturbs the existing flux. Structural material at the interface is assumed to be a low neutron absorber and treated as a void. In addition to causing peaks, the slab channel and its neighboring channels increase the average flux in the fuel-moderator region which may reduce significantly the peak to average flux.

Diffusion Equation. The one-velocity diffusion equation is solved in an infinite fuel-moderator region (assuming a homogeneous composition)

$$-D\nabla^2\varphi + \Sigma_a\varphi = S \qquad (1)$$

D is the diffusion coefficient; Σ_a is the macroscopic absorption cross section and S is the source or slowing down density. In an infinite region the slowing down density is equal to $\Sigma_a\varphi_0$ where φ_0 is the unperturbed or asymptotic flux distribution prior to the insertion of a slab water channel. Since Eq. 1 is linear, then for a one-dimensional slab in an infinite medium, the flux arising from the source in the fuel-moderator region can be treated independently of the flux arising from the presence of the channel so that the final flux distribution is the linear sum of two fluxes

$$\varphi = \varphi_0 + Ae^{-X/L} \qquad (2)$$

where L is the thermal diffusion length and A is a constant to be determined by the current condition at the boundary and X is measured from the channel interface.

An expression for A can be derived assuming that the channel is an infinite plane of zero thickness. This will be a good approximation for a real channel whose width is much smaller than a diffusion length (2.73 cm at 68° F) and which intersects other channels at distances greater than a few diffusion lengths in the fuel

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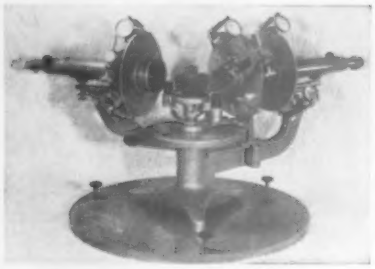

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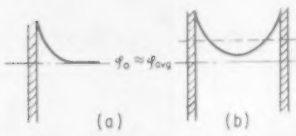

WATER-CHANNEL flux peaking effects. (a) Single channel in infinite medium (cross-hatched region) causes flux peak at channel but does not cause significant change in average flux level. (b) Channels with finite spacing cause both flux peaks and raise level of average flux

region. The absorption of neutrons within the slab region is ignored because the absorption is usually very much smaller in the channel than in the fuel-moderator region and this would make the problem much more difficult. Omission of the absorption acts as a safety factor in that the calculated peaking factor will be somewhat higher.

Channel source strength. Since neutrons slow down primarily by collision with hydrogen atoms, the slowing-down density in the channel region is assumed to equal the slowing-down density in the fuel-moderator region times the water volume fraction in the channel F_C divided by the water volume fraction in the fuel-moderator region F_F. Thus, the source is simply $(F_C/F_F)\Sigma_s\varphi_0$.

Channel-boundary current. The total current from a single thin slab will be the slowing-down density times t, the thickness of the water slab; one half of this current will flow in one direction. Thus, the current at the interface is $\frac{1}{2}(F_C/F_F)\Sigma_s\varphi_0 t$. Satisfying the current continuity condition at the boundary, permits the evaluation of A in Eq. 2

$$A = \frac{t}{2L}\frac{F_C}{F_F}\varphi_0 \qquad (3)$$

Thus the expression for the peak to average flux or power for an infinite one dimensional slab in an infinite medium is

$$\frac{\varphi}{\varphi_0} = 1 + \frac{t}{2L}\frac{F_C}{F_F} \qquad (4)$$

Intersecting Channels

For intersecting channels, each channel is again considered to be a linear independent source so one can simply add the contributions of each source. Thus, the expected flux for two crossed channels, each of thickness t, at the point of intersection is, $\varphi = \varphi_0[1 + (t/L)(F_C/F_F)]$. To generalize this solution for an odd number of semi-infinite channels, one can assume that the flux at any point along a line bisecting an infinite channel is the sum of fluxes from each half infinite plane. Taking one half-infinite plane away reduces the flux by one-half. Assuming the semi-infinite slabs to act independently of each other the flux at the point of intersection of m identical semi-infinite slabs of thickness t is

$$\varphi = \varphi_0\left(1 + \frac{m}{4}\frac{t}{L}\frac{F_C}{F_F}\right)$$

For a Y channel, the solution is

$$\varphi = \varphi_0\left(1 + \frac{3}{4}\frac{t}{L}\frac{F_C}{F_F}\right)$$

Finally, a further generalization can be made to account for the case of unequal width semi-infinite channels. The general expression for the peak-to-average flux at the point of intersection of N semi-infinite channels each with a thickness t_i

$$\frac{\varphi}{\varphi_0} = 1 + \frac{1}{4L}\frac{F_C}{F_F}\sum_{i=1}^{N} t_i \qquad (5)$$

Finite Geometry

The previous arguments are for slabs in an infinite medium. The increased flux or power produced in the fuel-moderator region because of channel has a negligible effect on the over-all average flux. However, if another channel is in the vicinity, the average flux is increased. This is illustrated for the parallel channel case in the figure. The introduction of another slab at distance $>3L$ (so that Eq. 2 is still valid) does not affect the peaking at the initial channel but does increase the average flux and so decreases the peak to average. To evaluate this effect, consider the case of a set of parallel slabs of thickness t separated by a distance $2y$.

Renormalizing the flux so that the same total power is produced between the two channels as was produced with no channels gives rise to a renormalized peak-to-average flux

$$\left(\frac{\varphi}{\varphi_0}\right)_N = \frac{1 + (t/2L)(F_C/F_F)}{1 + (t/2y)(F_C/F_F)} \qquad (6)$$

In the above expression as y goes to infinity, $(\varphi/\varphi_0)_N$ approaches the value for a slab in an infinite medium. To apply this renormalization concept to a complex geometry, one can interpret the denominator of Eq. 6 as

$$1 + V_C/V_F$$

where V_C is the volume of water in the channels and V_F is the volume of water in the fuel-moderator region. Thus one can generalize this renormalization factor to complex geometries and arrive at the final expression for the peak to average flux or power

$$\left(\frac{\varphi}{\varphi_0}\right)_N = \frac{1 + (F_C/4LF_F)\sum_{i=1}^{N} t_i}{1 + \frac{V_C}{V_F}} \quad (7)$$

A similar expression for a cylindrical water channel of radius R is

$$\left(\frac{\varphi}{\varphi_0}\right)_N = \frac{1 + \frac{R}{2L}\frac{F_C}{F_F}\frac{K_0\left(\frac{R}{L}\right)}{K_1\left(\frac{R}{L}\right)}}{1 + \frac{V_C}{V_F}} \quad (8)$$

Note that Eqs. 7 and 8 are only a function of the geometric configuration and one nuclear parameter, namely the thermal-diffusion length.

Equations 7 and 8 are derived from diffusion theory and it is generally acknowledged that one should not apply diffusion theory at boundaries. Also, numerous assumptions have been made in the derivation so that while these equations should be qualitatively correct, it would seem remarkable to expect high accuracy. Nevertheless, they seem to be able to predict peaking effects for the few cases* where it has been checked to within the experimental accuracy of the measurements. The reason for such good agreement is not clear except that diffusion theory usually gives good answers when it is valid everywhere within a region.

Also Eqs. 7 and 8 assume that the structural material that defines the channel is such a poor neutron absorber that it can be treated as a void. However, if stainless steel is the structural material, the absorption of the steel would greatly reduce the current from the channel depending on the thickness. Thus, one can eliminate channel peaking using an absorbing material between the water and the fuel-moderator region but at a cost of increasing the fuel loading.

Applications

Most reactors have a periodic geometry so that there is usually no difficulty in dividing the core into unit cells. If one considers a point adjacent to the control rod channel

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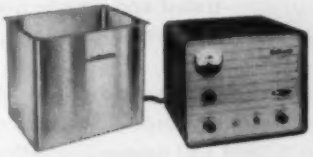

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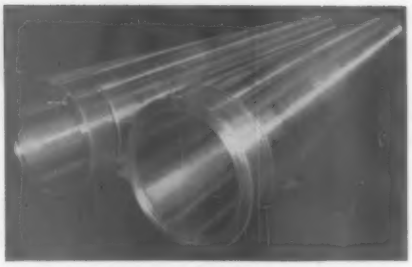

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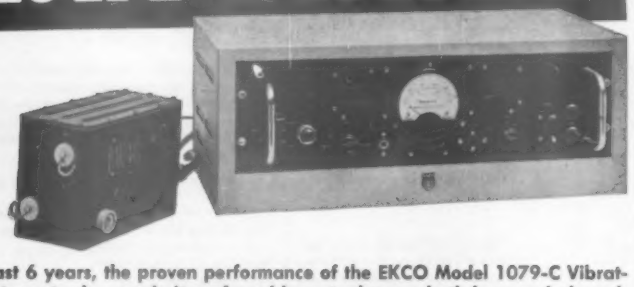

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near the center of the reactor where, because of radial and axial flux peaking, the temperature of the fuel or of the coolant is very close to the maximum design value, then it is desirable to minimize the channel peaking factor at this point. For example, a cross-shaped channel with equal-thickness arms, the peak to average is

$$\left(\frac{\varphi}{\varphi_0}\right)_N = \frac{1 + (t/L)(F_C/F_F)}{1 + (V_C/V_F)}$$

In principle, one has several parameters to vary for optimization; t, L, F_C/F_F and finally the total number and width of channels per unit cell. However, the latter is the only one that can vary without upsetting the entire reactor calculation. Two typical conditions are the following:

(a) If the fuel loading, metal-to-water ratio, and cell geometry are fixed and the control-rod thickness is fixed for control reasons, then the width of the control-rod channel with appropriate clearance is also fixed. Changing the distance between cells is the only way left to change the ratio of water in the channels. If the cells are in a square array with the cross-shaped channels between cells, then the cell spacing should be equal to the control-rod width. If cell spacing is made greater than the control-rod width, the worst peaking point will shift to the intersection of cells and the peak-to-average will not be optimum. We have assumed that the radial peaking factors are the same over a cell. If the cell is large enough so there is significant variation in these factors or channels first appear away from the center of the reactor, this information must be factored into the analysis.

(b) If for condition (a) the peaking is still too large, one can insert tails (metal filler) of low neutron absorption as the rods are withdrawn and reduce the total water thickness of the control-rod channel. In this case, the inter-cell spacing should be taken as the total water thickness of the control-rod channel.

The prime function of Eqs. 7 and 8 is to give physical insight into the parameters that govern the magnitude of peaking. In addition, they can be used in reactor calculations, both hand and machine, by considering the reactor as homogeneous and super-

imposing the detailed channel peaking. In some calculations, to calculate reactivity accurately the water channel can be treated as a separate region but not necessarily with the appropriate geometry. Then the resulting power distributions can be smoothed out and Eq. 7 or 8 used to superimpose the appropriate peaking. As an example for reactivity purposes a cross channel in the center of a cylindrical reactor can be mocked up as a cylinder. To get the peak flux, the peaking caused by the cylindrical channel would be subtracted out and a cross-channel peaking factor superimposed.

Bigger and Better Swimming-Pool Reactors

By PAUL N. GARAY

Atomic Power Equipment Department, General Electric Co., San Jose, California*

The trend toward higher fluxes and consequent higher powers in swimming-pool reactors has placed new problems before those charged with the design of nonnuclear parts of the system. From the many solutions that have been examined, I have chosen a few that may prove stimulating to others active in this area.

Radioactivity Problems

A limitation to successful high-power operation is the gamma radiation caused by Na^{24} in the pool. Considerable Na^{24} activity has been found in the Bulk Shielding Reactor (BSR) and in Materials Testing Reactor (MTR) and may be expected in the coolant of any reactor using aluminum in the core. The Na^{24} is produced by fast-neutron irradiation of the aluminum with the reaction $Al^{27}(n,\alpha)\ Na^{24}$ (15-hr half-life).

A concentration 2×10^{-9} ppm of Na^{24} in the average pool will result in a gamma dose rate at the pool surface of 60 mr/hr if the reactor has been operated at full power 8 hr a day for 5 days. The removal of this isotope from the water by a by-pass demineralizer should not be considered as an easy solution to the problem. Even assuming that all the Na^{24} can be removed in a deionizer, some 50 gal/sec of water must pass through the device to maintain acceptable radiation levels.

It has also been suggested that Al^{28} and Mg^{27} will contribute considerable activity to the pool, (315 mr/hr, at equilibrium). Even though these will decay to tolerance conditions within 15–90 min after shutdown of the reactor, they will constitute a problem during operation.

Another limitation on the operation of the swimming-pool reactor at high powers is the activity that is to be expected from the N^{16} in the pool water. The BSR had some difficulty with N^{16} radiation at power levels near 1 Mw that was partially solved by the installation of a diffuser arranged immediately above the core. This device limited the migration of N^{16} to the surface of the pool. With the short half-life, the brief holdup allows sufficient decay of the activity to prevent a serious hazard at the water surface.

In view of all of these radiation effects, it would appear that swimming-pool reactors cannot be operated at higher power levels than about 1 Mw. However, if suitable measures are taken the problem can be overcome to a large degree. Some of the possible measures include:

- A diffusion mechanism just above the core to limit cooling water circulation.
- Protecting the operator with shielding or taking him off of the bridge and putting him beside the pool instead of over it.
- A cover over the pool during high-power operation.

A metal-plate baffle just above the core will, of course, provide a relatively stagnant blanket of water over the baffle that will inhibit circulation up to the surface. Consideration also could be given to the use of a lighter-than-water liquid blanket that would attenuate radiation and, at the same time, provide a barrier to prevent

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FIRST IN ATOMIC POWER

This article starts on p. 99

water from circulating to the surface.

Such a liquid would have to be optically clear, nonmiscible with water, chemically stable, possessed of a high flash point, noncorrosive to metals in the system, and, of course, lighter than water. Several liquids are available that might be used for this purpose: some high-carbon alcohols, oleic acid, the higher ketones and various mineral oils. A 3- or 4-ft-thick layer of such liquids should have a very marked effect on the radiation level at the pool surface.

Some swimming-pool reactors have the control console mounted on a rolling bridge. By proper design of the control and instrumentation circuits, the console can be mounted on the floor besides the pool. This will allow the use of a lighter rolling bridge, and the operator will not be sitting over a hot pool. A moving-arm jib crane on the bridge would permit the elimination of the auxiliary bridge usually provided and still provide a means for suspending objects in the vicinity of the core.

Pool Structure

The large concrete structure of the pool poses some problems that have been indifferently solved so far. Good design should include concentric reinforcement around all penetrations.

The construction joints between successive days' pours should be carefully made. A 3-in. layer of grout of the same water-cement ratio should be deposited first and each subsequent placement started on a horizontal joint.

Shrinkage. Volume shrinkage of new concrete can be minimized by selecting cement for its shrinkage characteristics based on mortor specimens made with approximately the same water-cement ratio as is to be used on the job.

The mineral character of the aggregates will affect shrinkage; hard, dense materials will shrink but little, but sandstone mixtures may shrink quite a bit. The largest possible aggregates should be used, and the amount of water used should be kept to the minimum required for plasticity. The cement content should be kept as low as is compatible with strength requirements, and the whole should be mixed for as long a period as possible.

Each pour should be not more than 40 ft in any dimension, and about 10 days should be allowed between contacting pours. The concrete should

be cured promptly; the worst shrinkage is caused by excess water in mixing and too much water loss during curing.

Leakage. The possibility exists that leakage will occur around penetrations or inserts that have been inserted and grouted in openings provided in previously cast concrete. To prevent leakage, it is best that all pipes and inserts be cast directly into the concrete, or alternatively, that the grouting be done with an expansive cement.

Pipe penetrations in the pool and elsewhere should not be caulked with lead but with a mixture of asbestos and stainless-steel wool. Lead-bearing caulking materials can release lead to the pool water that will cause pitting in the aluminum-clad fuel elements. In addition, the pool should be lined, not only to prevent leakage or seepage, but to prevent surface absorption of radioactivity, which would provide a decontamination problem. Tile is an ideal material but is expensive. Some organic coatings are now on the market that show considerable promise for this purpose.

Thermal stresses. Gamma heating on the reactor side of the concrete pool structure will cause local stresses that will peak 12-24 in. inside the concrete structure. The temperature differential across a concrete structure, therefore, should not exceed 30–50° C.

One solution for this problem is to use an iron thermal shield at the hot face of the concrete. A cheaper solution is to use cooling pipes embedded in the concrete. These would provide simple passages for natural circulation of the water through the hottest sections. A third method would be to use double-wall pool structures. The double-wall, concrete pool structure will provide cheaper and more convenient construction in addition to providing a solution to the thermal-stress problem. A double wall having iron ore, or any other heavy, natural material, packed between the walls will provide a heavy, homogeneous shield and will permit the use of a smaller over-all structure.

Consideration may also be given to the use of a double-wall concrete pool structure so arranged that a head of water can be maintained between the two walls somewhat higher than the level in the pool. This arrangement would offset the leakage of radioactive water that would normally occur. With this water seal, leakage would be of clean water into the pool, or to the outside, with no attendant radiation problem.

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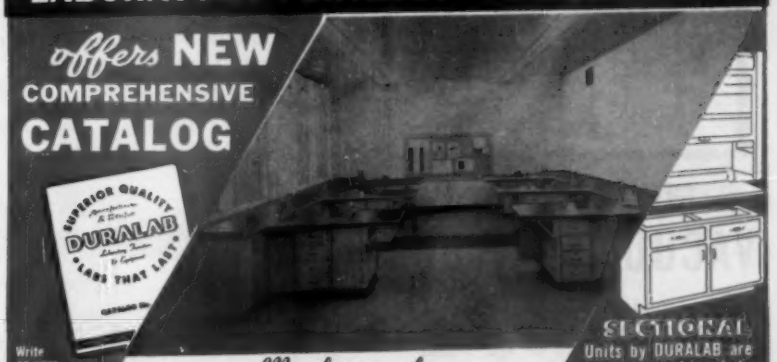

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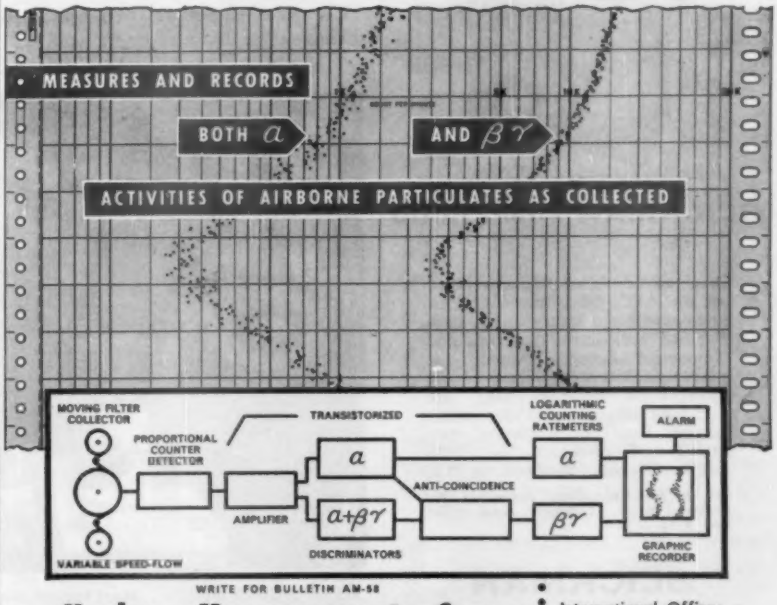

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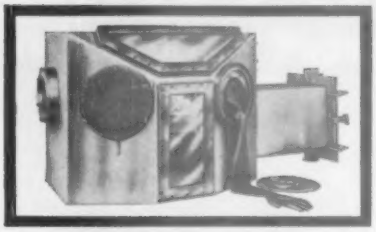

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APPLIED RADIATION

Cellophane Dosimetry Found Unprecise Green and blue cellophane can be used as dosimeters in the food-preservation range (0–2 × 10^6 rad), but their precision is not as great as that of other dosimeters. This is the conclusion of Samuel A. Goldblith and Richard I. Mateles of the Department of Food Technology at M. I. T. after comprehensive experiments with Du Pont 300 MSC Light Green and Light Blue Cellophane.

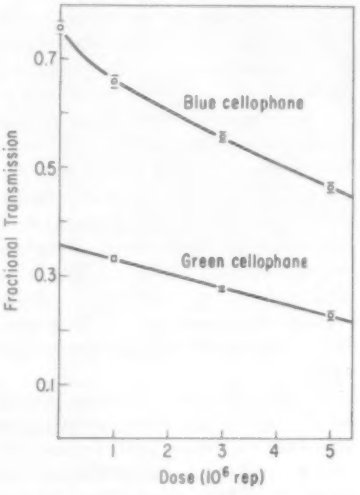
They assign the following probable errors after reducing random variation by reading the same spot before and after irradiation:

Dose (10^6 *rep*)	*Percentage error*	
	Green	*Blue*
1	15	20–30
2	10	12
3	4	7
5	6	4

They measured initial uniformity of both thickness and optical density, effects of storage before and after irradiation, and the change of optical density with exposure to 2.5-Mev Van de Graaff electrons. Optical density was measured at 6,500 Å for the blue and 6,100 Å for the green.

In thickness the green cellophane deviated from the nominal 0.001 in. somewhat more than the blue, but optical density deviated less for green than blue. The indication is that thickness variation is caused by colorless cellophane and absorbed water vapor while the amount of dye per unit area remains constant. Storage at 25° C and 50% relative humidity had no significant effect except that unirradiated cellophane darkened slightly. Its radiation sensitivity remained unchanged.

The curve shows the response of the two films to radiation dose and the corresponding limits of error.



Radiation response of cellophanes. Lines above and below experimental points indicate probable error. Here 1 rep = 0.93 rad of absorbed dose in cellophane

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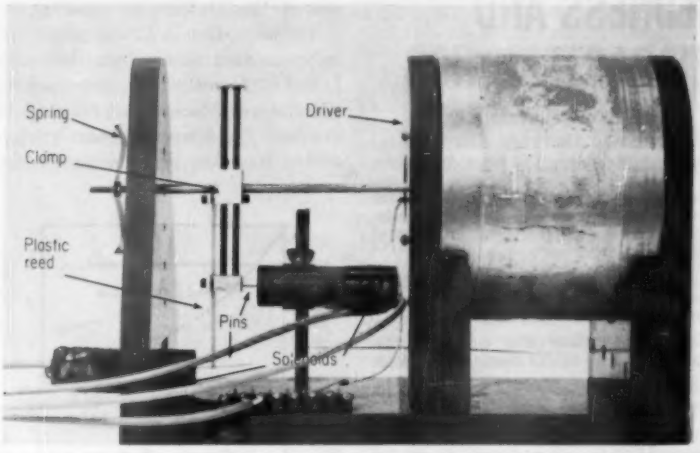

FIG. 1. Vibrating-reed mechanism vibrates plastic reed sample. Motion of iron pins attached to vibrating reed changes inductance of solenoids. When inductance effect is calibrated, it indicates mechanical properties of reed without destroying reed

Nondestructive Test for Radiation Effects

By J. D. MATLACK and S. STRELLA* *Picatinny Arsenal, Dover, New Jersey*

Past work on the effects of radiation on the mechanical properties of plastics involved the use of the standard destructive test methods (*1*), which necessitates a large number of samples. Further, the size and number of necessary samples per given exposure occupied valuable space in the radiation source.

For a small-scale study of radiation effects on the mechanical properties of plastics, we selected the vibrating-reed test (*2*). This dynamic mechanical test determines the elastic (E') and viscous components (E'') of the dynamic modulus of a material without destroying the test sample, thus permitting repeated exposure of the sample. The test has the further advantage in that the sample size is about $4.5 \times 0.2 \times 0.050$ in.

The dynamic-modulus test will not give the complete effects on the mechanical behavior. However, it will indicate at what dose levels significant changes in the material have occurred. The value of the test lies in that it will determine at what dose level significant changes have occurred, at which time such tests as tensile strength, melt index, solubility, etc., may be performed.

Vibrating-Reed Test

In the vibrating-reed device (Fig. 1), a rod is mounted on two springs (copper-beryllium strips, 10 mils thick, 1 in. wide, 7 in. long) so as to vibrate in the direction of the rod's axis. A clamp attached to one end of the rod holds the plastic reed being tested. The other end of the rod is coupled to a coil that protrudes into the magnetic field of a speaker-type permanent magnet. The output of an audio oscillator, amplified by a 30-watt amplifier, is fed to the coil to supply the vibratory motion of the rod.

An iron pin cemented to the free end of the reed extends into the core of an air-core solenoid. As the reed vibrates, the motion of the pin changes the solenoid inductance in proportion to the frequency and amplitude of the motion. After suitable calibration, the reed amplitude at any frequency can be determined by measuring the corresponding induced voltage in the solenoid. A similar solenoid setup is used to determine the amplitude of the clamp at the forced end of the reed.

With this information, the elastic (E') and the viscous (E'') components of the dynamic modulus can be calculated with the equations

$$E' = \frac{12\rho\omega_r^2[l^4 + (4m_p/\rho s)l^3]}{d^2} \times \left(\frac{16}{16a_0^2 - F^2}\right)^2$$

$$E'' = \frac{12\rho\omega_r^2 F\,[l^4 + (4m_p/\rho s)l^3]}{a_0^2 d^2} \times \left(\frac{16}{16a_0^2 - F^2}\right)^2$$

where $F = (-5.478 + 2\sqrt{7.502 + 6.15M^2})/1.689M^2$, M = ratio of free-end to forced-end amplitudes of reed at resonance, ω_r = resonant frequency (radians/sec), l = length of reed (cm), d = thickness of reed (cm), s = cross-sectional area of reed (cm^2), ρ = density (gm/cm^3), m_p = mass of pin and $a_0 = 1.875$.

Results

The curves show preliminary results

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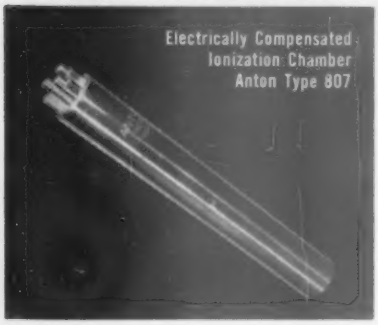

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of the irradiation of four commercial plastics by a 2×10^5-r/hr gamma-ray source (Figs. 2–5).

The large drop in E'' for polystyrene indicates that the material has crosslinked sufficiently to reduce markedly the flow or viscous behavior of the material (a lower viscous modulus means less flow, thus a more elastic

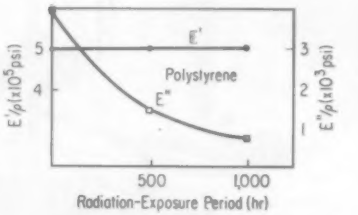

FIG. 2. Radiation effect on mechanical properties of polystyrene

material). Indeed, after a 1,000-hr exposure, the material became insoluble in benzene.

The increase in E'' for the phenolic material, after a 500-hr exposure, indicates that some of the crosslinks have

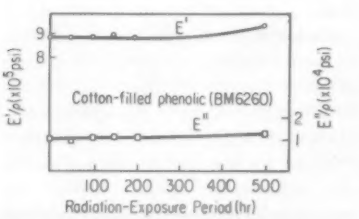

FIG. 3. Radiation effect on mechanical properties of phenolic material

been broken and that possibly the filler material has deteriorated.

Previous investigators (*3*) have pointed out that polyethylene crosslinks when exposed to high-energy radiation. Though the rises in both E' and E'' for polyethylene are not marked, they indicate that crosslinking is beginning to occur. However, the somewhat sharper rise in the viscous component may indicate that phenomena other than crosslinking are simultaneously occurring. The slow rise in these components also shows that a very large exposure will be necessary to produce marked changes in the mechanical behavior of polyethylene.

Polymethyl methacrylate was the most sensitive to radiation, with a

marked decrease in the elastic component and increase in the viscous component occurring sometime after a 200-hr exposure. Handling of the material after 500 hr showed that the material's tensile strength dropped to a very small value.

The data on the methacrylate polymer indicates one drawback to using the dynamic modulus as the sole index of the effects of radiation on the mechanical behavior of materials. The

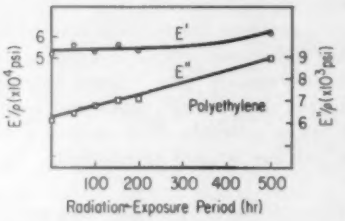

FIG. 4. Radiation effect on mechanical properties of polyethylene

much larger E'' and lower E' for the methacrylate would indicate a tougher material. The large drop in strength completely nullified this effect, thus giving a completely deteriorated material.

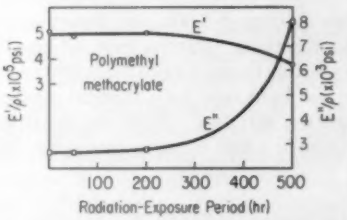

FIG. 5. Radiation effect on mechanical properties of polymethyl methacrylate

A program has been initiated with Stanford Research Institute that will utilize the reed test as an indicator of dose levels producing significant changes in two typical commercial polymers. At these levels, analytic methods will be employed to determine both the chemical changes and structural changes in the polymers.

* * *

The authors are indebted to Mr. Oesefort of Rock Island Arsenal for irradiating the plastics used in this work.

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2. S. Strella. Vibrating reed test for plastics, *ASTM Bulletin*, May, 1956
3. A. Charlesby. How radiation affects long-chain polymers, NUCLEONICS **12**, No. 6, 18 (1954)

RADIOACTIVITY AT WORK...#2

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Information about the method and radioisotope selected will soon appear in a scientific journal. For additional information on this and similar tracer studies, just write us. Our report on services for study of the reticuloendothelial system is also available.

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TECHNICAL ADVANCES

Reactor Spectra By Pulse Method

Calculations of reactor performance require a knowledge of cross sections averaged over the neutron spectrum for the reactor. In experiments at Harwell a section of reactor is being pulsed and time-of-flight measurements made of this spectrum in a beam extracted from the lattice. This gives direct information about the spectrum shape and about angular variations in the spectrum (relative to the line of the fuel elements in the lattice). Comparable experiments have been done with an unpulsed critical reactor and mechanical chopper (R. S. Stone, KAPL-1499). The pulsed source has two important advantages and one main disadvantage. Firstly, it gives freedom to design the all-important beam collimator without reference to any rotating element, and secondly, it gives the fuel a much smaller neutron dose. In a chopper experiment the fuel is irradiated for the whole of the running time, while a pulsed source only irradiates it during the useful time leading to $\sim\frac{1}{200}$ the irradiation typically. (An entirely different approach is provided by integral measurements using foil activation and fission chambers from which the reactor spectrum can be inferred. This method, while more convenient and free of angular effects give less detailed information.)

The disadvantage is that the time dependence of the neutron flux in an assembly is a function of this assembly. Pulses put in are stretched out to many times their original length, and the useful resolution (and even the possibility of making the experiment) depends on the particular lattice. No experiment is possible unless the effective pulse length is much less than the flight time. Many factors govern this condition, and each experiment must be examined on its merits. In general, water-moderated thermal systems and highly undermoderated systems (up to the intermediate reactor) are best investigated by pulsed source, while heavy-water and graphite-moderated systems require a chopper. The pulse shape from an assembly comprises a fast rise, followed by a nearly exponential decay (exactly exponential after higher harmonics have died away). The period of this exponential is taken as a measure of the pulse lengthening, and typical values are: pure water $\sim$200 μsec; water-uranium lattices (multiplication < 4), 100–200 μsec; graphite $\sim 10^4$ μsec, graphite lattices $\sim$5,000 μsec; heavy water $\sim 5 \times 10^4$ μsec. Using water lattices, and observing neutrons from a 1-cm-dia circle at 15 cm from the source, it has been possible to use a 12-m flight path with a source putting in 10^8 neutrons per pulse; the flight time for a thermal neutron is then 54,500 μsec, and that for a 1-eV neutron 820 μsec. With the larger accelerator under construction at Harwell, providing 10^{11} neutrons per pulse, the flight path can be 60 m.

Two further points must be considered before the measurements can be accepted. The first—common to all spectrum measurements in a subcritical assembly—is whether the spectrum is the same as that in a critical reactor, and the second, whether the spectrum in the assembly at a given point is the same as the spectrum in a beam extracted from that point. There has accumulated a good deal of experimental evidence that, provided loss of neutrons by absorption dominates loss by leakage, then the spectrum far from the source *is* characteristic of the lattice. However as the pulse lengthening is directly proportional to the multiplication in the lattice, it is important when using a pulsed source not to have too large an assembly and some compromise must be accepted. On the second point data is still being obtained by observing spectra of neutrons extracted in different directions relative to the lattice. Using water-uranium lattices spectra in both moderator and fuel have been observed in beams emerging along and normal to the fuel rods. In nearly all cases the spectra has a Maxwellian component, characterized by a temperature T, which is distorted at its high energy end and eventually joins to a $1/E$ slowing down spectrum. In the moderator the spectrum taken normal to the bars contains a stronger Maxwellian component than that along the bars (15% more thermal neutrons in one case observed) while in the fuel the same effect is seen, and in addition the Maxwellian is distorted. Plans have now been made to measure the spectrum in six directions.

* * *

We are indebted to M. J. Poole of AERE, Harwell for this account of his experiments.

BOOKS

Nuclear Stripping Reactions

By S. T. BUTLER and O. H. HITTMAIR (John Wiley & Sons, New York, and Horwitz Publications, Sydney, Australia, 1957, ix + 130 pages, $8.75).

Reviewed by W. TOBOCMAN, Department of Physics, The Rice Institute, Houston, Texas.

The idea of deuteron stripping, a nuclear reaction in which only one of the two particles making up a deuteron interacts directly with the target nucleus, was first suggested by Oppenheimer and Phillips in 1935. In the last few years new interest has been aroused in the subject as a result of the work of S. T. Butler and of Bhatia, Huang, Huby and Newns. These people found that it was possible to interpret the angular distributions of *d-p* and *d-n* reactions in the medium-energy range on the basis of the stripping hypothesis. Thanks to their analysis, it is possible to use *d-p* and *d-n* reactions to get information about the spins and parities of nuclear states. This development has played an important part in verifying the predictions of the shell model.

"Nuclear Stripping Reactions" is the first book to be written on the subject of the theory of the stripping reaction. The subject is old enough so that this book, with its clear exposition of the theory, will be welcome to those trying to learn the subject for the first time as well as to those who have been in the field long enough to be confused by the large number of papers deriving the same theory in a different way. On the other hand, the subject is new enough so that a book published at this time could not fail to contain many controversial passages.

In the first chapter we have a very readable introduction to the theory of the stripping reaction in which the results of the theory are presented in terms of simple semi-classical arguments. In the second and third chapters, Butler derives the stripping theory following the method he used in his own work. Two derivations of the theory are given in chapters 10 and 11. I think it is unfortunate that Butler presented three different derivations of the theory since the physical content of the three methods is identical. It is particularly unfortunate, though altogether natural, that Butler chooses to emphasize his own approach to stripping theory, which is the most cumbersome and complicated of the three methods described.

Following the derivation of the theory there are three chapters devoted to the nuclear-distortion effect and the Coulomb-distortion effect. These effects are neglected in the simple theory but can be included in a more rigorous treatment. The only stripping calculation I know of in which these effects are both taken into account is one by M. H. Kalos and myself. More calculations of the same sort have to be done before one can give a final answer as to the limits of validity of the simple form of the theory, which neglects these effects. However, in this matter I must take issue with Butler since his interpretation of our results differs from our own. Butler states that the effects are small for sufficiently high incident-deuteron energy. My own interpretation of these calculations is that these effects are quite large and that the simple theory works because of a cancellation between these two effects. The one graph taken from our paper, which is reproduced in this book, gives, I think, the wrong impression of the general trend of our results.

Following the discussion of the nuclear and Coulomb corrections, there are chapters devoted to reduced width determinations by stripping, angular correlations in stripping, and polarization effects in stripping. Finally there is a chapter on the pick-up reaction and one on surface reactions in general. Missing from the book is any discussion of exchange effects in stripping. A second glaring omission is the lack of an index. The bibliography also has many important omissions.

I think the book is an excellent summary of stripping theory, and I am sure nuclear physicists will find it very useful. However, I feel that the point of view that pervades the work is unnecessarily narrow and conservative. The author regards stripping theory as a tool of nuclear spectroscopy that should be used only in those conditions where it is known to be valid. Investigation of corrections to the simple theory, according to Butler, is only useful in fixing the limits of validity of the simple theory but cannot itself teach us anything new about nuclear interactions. If this were so, Butler's book would not only be the first book on stripping theory but also the last.

I am sure this will not be the case.

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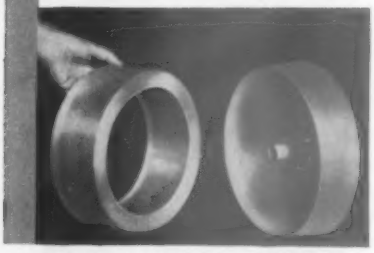

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BOOKS

Department starts on page 107

Deuteron stripping has revealed to us a whole new aspect of nuclear interactions—one that is completely different from and complementary to Bohr's compound nucleus model. This new aspect of nuclear interactions, often referred to as the direct-interaction model, is quite consistent with the picture we get from the shell model and the optical potential model. Thus I think the subject should be pursued for its own sake and will indeed teach us more about nuclear interactions. We are still far from a true understanding of the basic assumptions of the theory. Semi-classical arguments like those used by Butler are very helpful guides, but they are not substitutes for calculations of higher-order effects.

BOOKS RECEIVED

Conference papers available. Papers presented at the Atomic Industrial Forum conference on "The 1957 Nuclear Industry" are listed in a catalog available from AIF. Subject areas are research, test and power reactors; fuel; uranium production; radiation applications; and managerial problems. *Atomic Industrial Forum, 3 E. 54th St., New York 22, N. Y.*

Progress in Semiconductors—2, edited by A. F. Gibson, P. Aigrain and R. E. Burgess (John Wiley & Sons, New York, 1957, vii + 280 pages, $10.50). This book is comprised of eight papers. Of special nucleonic interest is *Radiation Effects in Semiconductors* by J. H. Crawford and J. W. Cleland (42 pages); studies of fast-particle bombardment are reviewed, including much unpublished data. Other chapters include *Semiconductor Alloys, Properties of the III-V Compound Semiconductors, Lifetimes of Free Electrons and Holes in Solids,* and *Theories of Electroluminescence.*

Progress in Nuclear Physics, Vol. 6, O. R. Frisch, editor (Pergamon Press, London, 1957, 297 + vii pages, $14). This latest in the Pergamon series again underlines current advances in nuclear physics. Timeliness is indicated by an article by Frisch and Skyrme: "Parity Non-conservation in Weak Interactions." Multistage isotope separation is reviewed by T. F. Johns and electromagnetic separation by M. L. Smith. Other articles are on nuclear models, moments and spins, atomic masses and fission recoil.

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Recorder outputs are provided for amplitude and integrated value. Total desired integrated value can be preset, making the CI-100 useful as a control device.

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ACCURACY	Current amplitude ±0.2% Charge ±0.8%
CURRENT RANGE	3×10^{-9} to 10^{-3} amperes
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LETTERS

East-West Open House

The editorial in the April '58 NUCLEONICS *suggested that the opportunity exists to foster good relations between East and West in the atomic energy field. Particularly effective would be an exchange of scientific teams. In the U. S. many laboratories and facilities are unclassified. There therefore should be no insurmountable obstacle to Russian visitors.*

A reader comments:

DEAR SIR:

I like your "Candor Before Geneva" editorial. If the suggestion is adopted, I think it is extremely important to reach an understanding at an early date about which specific laboratories the U. S. delegation would visit and which reactor projects would be discussed. Otherwise, the U. S. delegation is likely to get a pleasant visit to two or three Moscow laboratories and Obninsk. This is not what I would consider a fair exchange.

—ARNOLD KRAMISH
Physics Division
The Rand Corporation
Washington, D. C.

VBWR = $2,500,000 +

DEAR SIR:

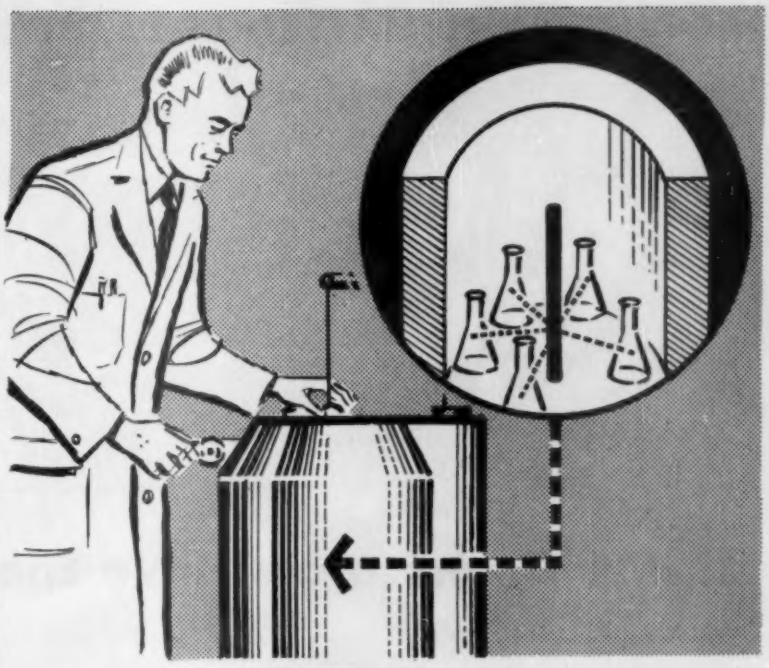
You and your staff are to be congratulated on the excellent coverage given our Vallecitos Boiling Water Reactor in the February NUCLEONICS (p. 76).

We would, however, like to point out that the cost figure of $2,500,000 you quoted for the reactor, while correct in essence, must be qualified. It is only the bare cost and does not include such items as cost of land, supporting facilities, commercial and administrative expenses and other miscellaneous expenses that would be involved were it a purely commercial facility.

We are very proud of the fact that the reactor was built within the cost estimated at the time construction was started and within the time allotted.

Incidentally, while writing of reactor construction costs, I would like to point out that, contrary to some current published estimates, the costs for our Dresden project are still within those estimated at the time the contract for this station was signed in 1955.

—J. E. MAIDER, Manager
Marketing and Project Operations
Atomic Power Equipment Department
General Electric Company
San Jose, California



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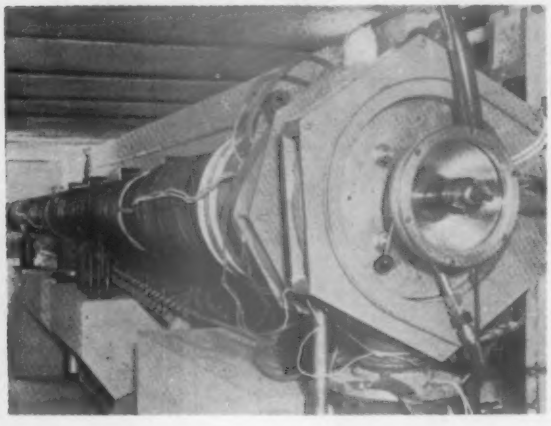

Outputs of 2-Section Linacs

	First section			Second section		
Length of guide (ft)	*Energy (Mev)*	*Peak power (Mw)*	*Mean power (kw)*	*Energy (Mev)*	*Peak power (Mw)*	*Mean power (kw)*
19.7	20	0.4	0.6	13	0.45	0.65
10.8	13	1.1	1.57	15	1.28	1.83
10	8	2.4	3.45	9	2.7	3.85
9.2	7	2.45	3.5	8	2.8	4
6.3	5	2.5	3.5	5.6	2.8	4
5.3	4.1	2.5	3.5	4.65	2.9	4

Linear Accelerators Have Energies to 1 Bev

Three operating electron linear accelerators (Models LE 0.08, LE 28, above, and LE 101) are powered by 3,000-Mc klystrons and magnetrons and have output energies from 1 Mev to 1 Bev. The table shows output currents and energies available from two successive accelerating sections.

Smallest of the operating Linacs is the LE 0.08 with a 10-Mev maximum energy. Peak currents are 100 ma at 4.5 Mev and 15 ma at 7 Mev. R-f energy of 900 kw is supplied by a 1-Mw tunable magnetron manufactured by the maker of the accelerator.

The LE 28 offers 85-ma peaks at 28 Mev and produces up to 10^{13} n/sec. Pulses of 2, 1, 0.5 and 0.25 μsec can be had at repetition rates of 500, 250 and 125 cps. Two 3-cavity klystron amplifiers supply 4-Mw peak power each. They are driven by another klystron of the same type acting as an oscillator. Both the LE 0.08 and the LE 28 are in operation at the Saclay research center.

Larger still is the LE 101, installed at the Ecole Normale Supérieure in Paris. It uses 16 of the company's klystrons, each supplying 20-Mw peaks. Maximum energy is 1 Bev, but the beam can be taken out along the accelerating sections at lower energies of 250, 500 or 750 Mev.—Compagnie Générale de Télégraphie sans Fil, Paris, France (U. S. distributor, American Radio Co., 445 Park Ave., New York 22, N. Y.)

Paper Chromatograph

"Hi-Speed" chromatograph (above) cuts normal separation time to 5 min. Centrifugal force is used to accelerate separation and permit multiple samples to be run simultaneously. Flow rate is held to less than 1 ml/min by stainless-steel precision-bored capillary. It has provision for 300–1,550-rpm speeds and handles paper up to 35 cm in diameter.—Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.

C^{14}-Labeled Compounds

Potassium cyanide-C^{14} in crystalline, alkali-free form and the following C^{14}-labeled compounds are available for prompt delivery: sodium bromoacetate-1, sodium bromoacetate-2, guanido acetic-2 acid (clycocyamine), phenoxyacetic-1 acid, phenoxyacetic-2 acid.—Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.

Cobalt-60 Irradiator

Model D-47 has push-button control of drawer motion and automatic removal of samples. Sample cavity of this medium-sized irradiator has 6-in. diameter and is almost 8 in. high. Up to 8,000 c cobalt-60 (dose rates up to 10^6 r/hr) can be used safely. Weight is 7,000 lbs, floor space required is 16 sq ft and over-all height is 76 in.—Atomic Energy of Canada Ltd., Ottawa, Canada.

Pressure Transducer

Series of variable-reluctance pressure transducers (above) are of stainless steel construction. Model DP-27 is for differential pressure measurements in ranges from ±7.5 to ±2,000 psid. Model AP-27 is for absolute pressure measurements in ranges from 0–5 to 0–1,000 psia. Transducers will withstand over-range pressures of twice full scale. Hysteresis is 0.5% of full scale or less for ranges up to 100 psid and 1%

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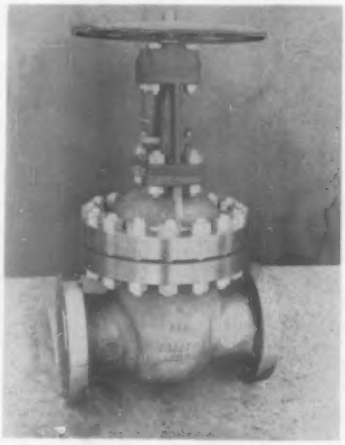
PRODUCTS & MATERIALS

Department starts on page 110

or less for higher ranges. Linearity is ±1% of full scale or better. For temperatures of −65°–+250° F, zero shift is 0.02% of full scale per degree and sensitivity change is 0.04% full scale per degree without compensation. With compensation, variations in both zero and sensitivity can be reduced to <0.01% full scale per degree. Output is ±40 mv per volt (compensated) and ±55 mv per volt (uncompensated).—Northam Electronics, Inc., 2420 N. Lake Ave., Altadena, Calif.



Stainless Gate Valves

Series of 600-lb stainless-steel gate valves (above) designed to meet API 600 and ASA B 16.5 specifications are produced in sizes ½–2 in. screwed and socket weld and ½–8 in. flanged and butt weld and have a pressure range of from vacuum to 1,440 psi, a temperature range of −425°–1,500° F with proper packing.—Cooper Alloy Corp., Hillside, N. J.

Gas Analyzer

Model 7C is industrial, thermal-conductivity, gas analyzer for continuous monitoring of nitrogen, hydrogen, argon or carbon dioxide in wide variety of gas mixtures. Response time is 30 sec for 95% of change at sample flow rates of 250 cm³/min. Single or multiple ranges from zero to 0.5% and zero to 100% full scale are available as is indicating meter with accuracy to 2%.—Process Instruments Div., Arnold O. Beckman, Inc., 2500 Fullerton Rd., Fullerton, Calif.

Vacuum Sintering Furnace

Series of induction-heated high-vacuum sintering furnaces with temperature capabilities of 2,000–2,600° C

use graphite, molybdenum or tantalum susceptor, depending on application. Complete instrumentation for temperature control and recording is provided.—F. J. Stokes Corp., 5500 Tabor Rd., Philadelphia 20, Pa.

Flexible Insulation

Wrapping and bonding woven ceramic fiber tape around pipes as small as ½ in. in diameter with zirconium-base cement forms positive, shock-resistant insulation that withstands temperatures to 2,000° F. Tape can be supplied with two nickel-chrome wire strands so that leakage from pipe carrying metallic or radioactive fluids provides conducting path and sounds alarm.—The Russell Manufacturing Co., 632 E. Main Street, Middletown, Conn.

Scanning Count Integrator

Model 540 is scanning count integrator designed for automatic histogram plotting of spectral information. Accuracy of the spectra obtained is within 1% on all 9 ranges from 0–30 counts full scale up to 0–300,000 counts full scale. Other characteristics include range multiplier by integers from 1 to 4 and output drive for all standard recorders.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Bellows Coupling

Model T9 (above) is stainless-steel zero-adjustable bellows coupling that allows precision adjustment on sensitive shafts of servo motors, resolvers and synchros. It is designed for 360-deg continual rotation and adjustment and is adaptable to four basic shaft sizes: 1/8, 3/16, ¼ and ⅜ in. applied on pin- and clamp-type hubs.—PIC Design Corp., 477 Atlantic Ave., East Rockaway, N. Y.

Hot Potentiometer

Trimmer-type "FilmPot" potentiometers, able to operate effectively in temperatures as high as 400° C, have been designed for use in nuclear propelled aircraft. Rectangular (2 in. long, ½ in. wide and ½ in. high) it has as resistance element continuous film of

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Model 727 Logarithmic Count Rate Meter. Wide range, five decade instrument for use with all types of radiation detectors. Range 10 to 1,000,000 counts per minute. Scale expansion feature for extreme sensitivity and accuracy when used with recorder readout.

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Model 751 DD-2 Non-Overload Linear Amplifier for scintillation spectrometry, reactor control, etc., and other applications requiring high gain, fast resolution, good linearity, and fast overload recovery.

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(ORNL Q1192)

Model 695 Single Channel Differential Analyzer. A differential pulse height analyzer for separating pulses of varying amplitudes.

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(ORNL Q1743)

Model 762 one microsecond Hi-Speed Scaler is designed for counting pulses from nuclear detectors. Permits counting pulses at high rates with extremely low coincidence loss. Use of decade counting circuits increases reliability and gives low power consumption.

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Model 672A, A1D Linear Amplifier for amplifying low signal level pulses from radiation detectors such as ionization chambers, proportional and scintillation counters.

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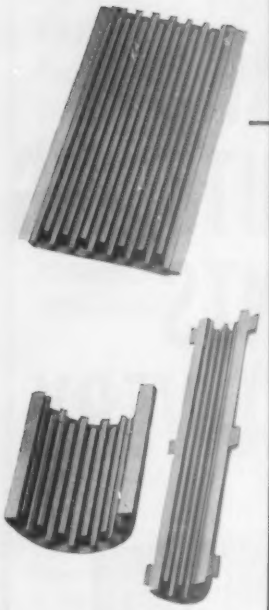

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evaporated rare-metal alloys. Besides infinite resolution, it has a stable resistance of better than 5% up to 30 k from −55° to 400° C at 300 v.—Fairchild Controls Corp., 225 Park Ave., Hicksville, L. I., N. Y.

Rate-of-Change Computer

Model 0557-1 (above) measures rate of change of slowly varying, low-level voltage changes of d-c signals (10–5,000 μv/sec superimposed on static voltages of 0–100 mv). Typical nuclear application is measurement of temperature buildup in increments of as little as 0.5° F/sec. Computer includes high-grain d-c differential-chopper amplifier with completely floating high-impedance input, transistorized rate unit, 400-cps power supply for the choppers and regulated d-c supply. Unit is 7 in. high and fits standard 19-in. relay rack.—Magnetic Instruments Co., 546 Commerce St., Thornwood, N. Y.

Low-Level Counting System

Model 774 low-level counting system (above) has provision for maximum reduction of background by complete cylindrical enclosure in single multi-anode anti-coincidence shielding counter. Plastic construction minimizes conversion gamma rays. System was engineered for counting-sample systems consisting of (1) dual soft-beta

counter unit, (2) low-level Geiger internal gas-counter unit and/or (3) low-level proportional internal gas counter. —Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.

High-Temperature Switch

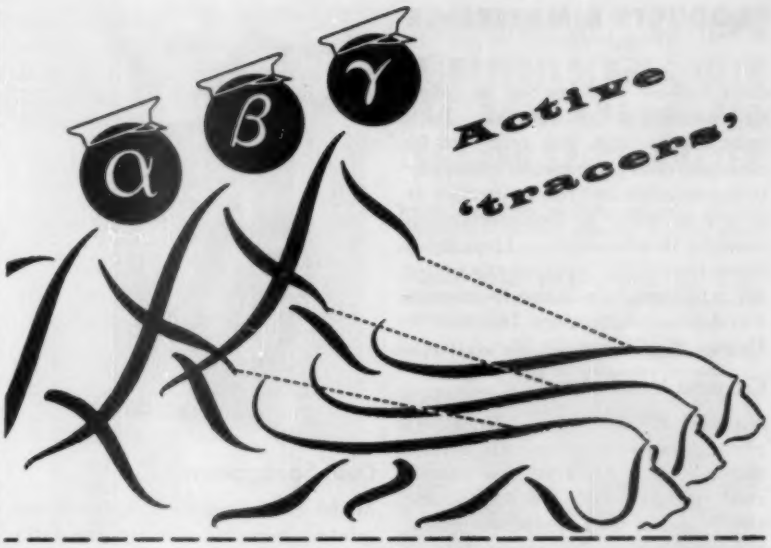
Small, precision switch has minimum life of 25,000 operations at 600° F and offers these features: maximum dimensional stability, ability to withstand repeated shock and vibration, resistance to moisture and humidity, resistance to radiation, and complete resistance to formation of radioactive by-products. The contact arrangement is single-pole double-throw and can be wired either normally-open or normally-closed.—Micro Switch Div., Minneapolis-Honeywell Regulator Co., Freeport, Ill.

100-Channel Analyzer

Model PHA-100/20 pulse-height analyzer (above) consists of 100-channel analog-to-digital converter plus twenty storage channels. Uniformity of channel width without adjustment and accurate alignment of the end channels of twenty-channel groups are features. Any twenty-channel group can be selected for storage of data by single switch setting. Linearity is 0.5%; deadtime is 500 μsec.—Tullamore Electronics Laboratory, 6055 S. Ashland Ave., Chicago 36, Ill.

Memory Core Analyzers

Model 3300 (100-channel) and Model 3302 (200-channel) memory-core analyzers accumulate data for preset time (corrected dead-time or clock-time) with automatic print-out cycle. Storing and printing cycle repeats automatically so that sample changer can be programmed to change samples during each print-out, or successive



Several hundred isotopically labelled compounds are now produced regularly at Amersham. They include an unrivalled range of materials needed for tracer work in biology, pharmacology, medical diagnosis and therapy, and in many technical applications of chemical products—pesticides, weedkillers, hormones, and the like.

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Surface-active Agents :	Potassium ethyl xanthate-S35 Sodium di-*iso*amyl sulphosuccinate-S35 Sodium lauroylmethyltauride-S35 Sodium lauryl sulphate-S35

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short half-life readings can be taken automatically at fixed intervals. Both units can be split into groups of 50 channels, each programmed externally to tag radiation by type or direction or to use as many as four scintillation counters simultaneously. Linearity is better than 0.5%; input counting rates are $>10^6$ cpm.—Radiation Instrument Development Laboratory, Inc., 5737 S. Halsted St., Chicago 21, Ill.

Gamma Irradiator

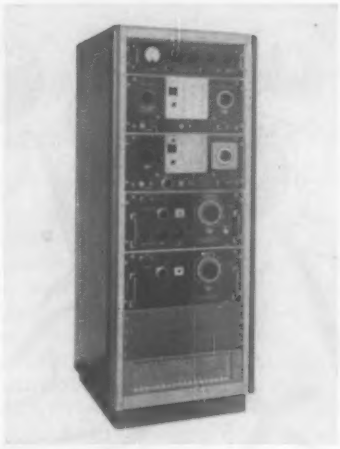
Nucor "HERO" series high-flux gamma irradiator for applications from 600 to $>2 \times 10^6$ r/hr has welded-steel case and such low surface flux that it can be used in office or laboratory without special construction or connections.—Isotopes Specialties Co., 170 W. Providencia, Burbank, Calif.

Automatic Pressure Logger

Data-Master Type 5 is automatic, digital data logger (above) that scans sequentially 24 or 48 pressure lines into a single transducer, thereby eliminating multiple transducers. Low switched volume results in more accurate pressure measurements by minimizing air flow disturbance at probe orifice and pressure drop at probe orifice and in pressure line. Specifications are: scanning rate, 4 points/sec; accuracy, ¼% (including transducer); repeatability, 0.1%; range, 0–350 psi; switched volume, 0.1 in.^{3}—Hanson-Gorrill-Brian, Inc., 85 Glen Cove, New York.

Thickness Tester

Model D-2 "Dermitron" has been developed for measurement of coatings, cladding and films. A portable, electronic instrument, based on eddy-current principle, it can measure nonmagnetic metal combinations such as zirconium on uranium fuel elements. —Unit Process Assemblies, Inc., 61 E. 4th St., New York 3, N. Y.

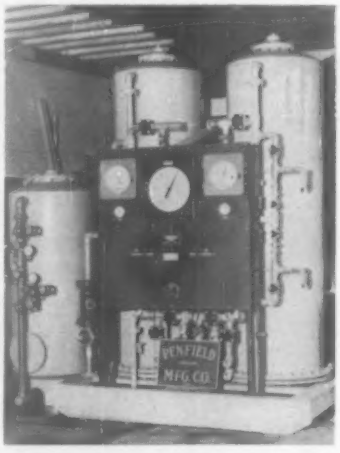


Dual Spectrometer

Model S-13 Dual-Peak spectrometer (above) measures directly the ratio between two separate isotopes in the same radioactive sample using two scalers, two single-channel analyzers, power supply, linear amplifier and preamplifier. Pulses from each isotope are put into separate single-channel analyzers and scalers.—Technical Measurement Corp., 140 State St., New Haven, Conn.

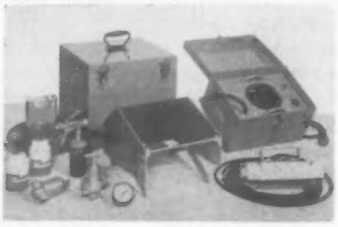
Decontaminating Unit

Model DEC-50 portable decontaminating unit consists of single-switch, one-knob control; space-saving generator with carrying handle; and transducerized tank. Tank, made of 18-8 stainless steel, has rounded corners for easy cleaning and ½-gal cleaning compartment (9 × 5¾ × 5¾ in.).—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.



Demineralization System

Continuous-flow demineralization system (above) offers delivery of 50 gpm of ultrapure process water of 18 to 20 meg resistance. System consists of twin mono-column demineralizers and carbon pre-filter. Operation is completely automatic; only manual attention required is refilling regenerant tanks. Effluent conductivity is both visually indicated and recorded. If effluent being delivered to service line falls to predetermined danger point, units automatically deliver to drain.—Penfield Manufacturing Co., 19 High School Ave., Meriden, Conn.

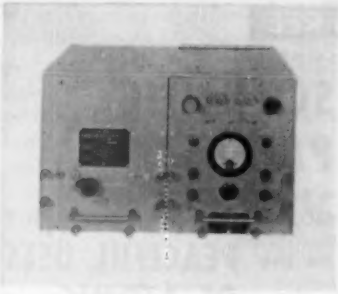


Nondestructive-Test Kit

Bondcheck BC-1 Inspection Kit (above) can be used on metallic honeycomb, soldered, welded or brazed surfaces. Test procedure begins by cleaning part surface and then spraying on specially formulated red fluid that is repelled by heat and tends to flow to coolest area on metal surface. Next, controlled heat is applied from high-intensity infrared lamp. Heat is conducted away wherever good bond exists causing fluid to accumulate there. Areas of defective bond are visible as gaps in pattern.—Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill.

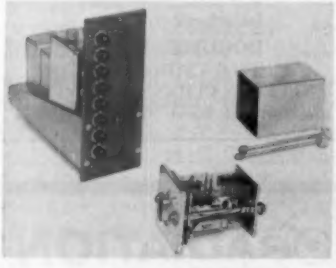
Paper Chromatograph Scanner

Model PCS-1 paper chromatograph scanner (above) provides faster and more accurate chemical analysis of C^{14} and other soft-beta-emitting compounds. It also detects beta-gamma emitting isotopes such as S^{35} and P^{32} and, when operated as proportional counter, senses alpha radiation as well. Either strip or two-dimensional chromatographs are handled automatically. Scanner incorporates detector, scaler, recorder and scanning mechanism.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.



Particle Monitor

Particulate-contamination monitor (above) includes continuous and automatic circuit-failure indicator for all vital circuits. Transistorized unit has minimum of lead shielding because built-in electronic compensation unit keeps background gamma radiation from affecting readings. Logarithmically calibrated scale covers range of 5×10^{-10} to 1×10^{-6} mc/cm^3.—Fairchild Camera & Instrument Corp., Robbins Lane, Syosset, Long Island, N. Y.



Automatic Scanning System

Monitron is automatic alarm and control system that gathers alarm and control data from remote stations and transmits it to central station at predetermined rate ranging from 0.2–0.02 sec/step.—Moore Associates, Inc., 2628 Spring St., Redwood City, Calif.

Low-Background Shield

Model 800D (above) is radiation shield composed of four separate, stacked sections to form various complete units for thin-window flow counting, G-M and scintillation counting. It provides minimum of 3 in. of iron shielding in all directions.—Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.

Shipping-Drum Pump

Air-powered pump of stainless steel (above) permits minute quantities or volume delivery of fluids directly from 2-in. end bung (or open head) of original shipping drum.—Gray Co., Inc., 1016 Sibley St. N. E., Minneapolis 13, Minn.

Radiography Unit

Model MG 100 (above) is portable, industrial X-ray radiography unit. Radiation angle of 42 deg allows wide field coverage that amounts to 76% of the focal-film distance. At full load (100 kv at 4 ma), it can be operated 50 min.—Philips Electronics, Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

Swaged Thermocouple Assemblies

Assemblies are designed for high-pressure, severe-vibration, corrosive, or extreme-temperature applications; consist of thermocouple wires surrounded by a ceramic insulation and encased in a metallic sheath. Ceramic can be magnesia, alumina, or zirconia. Sheath can be supplied in Inconel, Monel, aluminum, copper, and various types of

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Although the Tri-Carb Liquid Scintillation Spectrometer is sensitive enough to be used for natural radiocarbon dating of preserved organic materials that are over 40,000 years old, it is still simple enough to be used for counting hundreds of ordinary samples per day. Obviously the possibilities for practical industrial applications of radioactive tracers are greatly enhanced now that measuring equipment with this inherent sensitivity is available for routine use. Costs, safety, etc., cease to be limiting factors, and even the labeling of consumer products becomes a practical consideration.

For additional general information request Bulletin 314. For specific information on your requirements, provide application details.

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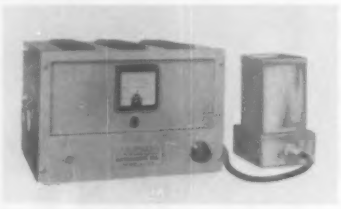
PRODUCTS & MATERIALS

Department starts on page 110

stainless steel. Assemblies are 0.032–0.3125-in. o.d. with tolerances to ±0.0005.—Advanced Dynamics, Inc., 16321 Rockside Rd., Maple Heights, Ohio.

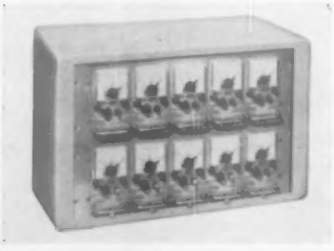


Ultrasonic Cleaner

Low-cost 50-watt ultrasonic cleaner (above) for small part cleaning, blind hole washing, removal of radioactive contamination, etc. Stainless steel tank is 6 × 6 × 6-in.—Alcar Instruments, Inc., 17 Industrial Ave., Little Ferry, N. J.

Thermocouple

Leak-proof high-pressure thermocouple (above) for use in systems with pressures to 80,000 psi and temperatures to 1,000° F is designed for installation in vessels where ¼- ⅜- and 9/16-in.-dia openings are provided. Assemblies consist of iron-constantan or Chromel-Alumel couple welded at the tip. Plug and sheath of thermocouple tip are of type-347 stainless steel.—American Instrument Co., 8030 Georgia Ave., Silver Spring, Md.



Monitoring System

Designed for continuous area monitoring around reactors, hot cells, etc., system (above) gives automatic alarm when radiation reaches preset level. Designated RAM (Remote Area Moni-

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tor), standard units cover any three consecutive ranges of gamma radiation between 10^{-2}–10^{6} r/hr. Beta-gamma range is from 1 mr/hr to 10^{5} r/hr. Gamma energy response is independent within ±10% from 80 kev to 2 mev; accuracy exceeds ±15% of actual intensity over entire range. Response time is ~10 sec at 1.0 mr/hr.—The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

High-Speed Scaler

Model 762 Hi-Speed scaler (above) consists of input pulse-height discriminator, fast scale of 10, three slow-speed counter decades and six-digit electromechanical register. Fast scale uses Burroughs beam-switching tube capable of $>10^{6}$ cps. Slow-speed decades are dekatron counter tubes capable of 5,000 cps. Resolving time (pulse pairs) is <1 μsec, coincidence loss is <0.2% measured at 20,000 random cps. Count capacity is 10^{10} with 10^{9} displayed.—The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Pulsed Neutron Generator

Pulsed neutron generator consists principally of vacuum system, ion source for the production of deuterons and various electrodes for extraction and acceleration of the beam of ions to energies up to 100 kev. At this energy the ions strike a target containing deuterium or tritium and produce neutrons by a nuclear fusion reaction. Neutron yield at the target exceeds 6×10^{5} n/sec from $2H(d,n)He^{3}$ reaction. Yields in excess of 6×10^{7} n/sec can be obtained with $H^{3}(d,n)He^{4}$ reaction.—Atomic Laboratories, Inc., 3086 Claremont Ave., Berkeley 5, Calif.

LITERATURE AVAILABLE

Accessories for nuclear field are included in 18-p Catalog A.—Atomic Accessories, Inc., 244-02 Jamaica Ave., Bellerose 26, N. Y.

Scintillation phosphors are subject of 40-p booklet that contains up-to-date information on characteristics of scin-

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PRODUCTS & MATERIALS

Department starts on page 110

tillation phosphors, typical gamma-ray spectra, bibliography, etc.—The Harshaw Chemical Co., 1945 E. 97th St., Cleveland 6, Ohio.

Rolling mill for both hot and cold processing of nuclear metals is shown in 12-p Bulletin 1057.—Stanat Manufacturing Co., Inc., 500 Shames Dr., Westbury, N. Y.

Fuel-element bibliography contains more than 300 references with abstracts.—Sylvania-Corning Nuclear Corp., Bayside, N. Y.

"Radiation Effects and Electronic Devices" is title of 4-p pamphlet.—American Nuclear Science Corp., 61 Broadway, New York 6, N. Y.

Pressure vessels, tanks, piping, etc. are subjects of 8-p Bulletin 550.—L. O. Koven & Brother, Inc., 154 Ogden Ave., Jersey City 7, N. J.

Miniature inspection lamps and accessories are covered in two 4-p bulletins.—Eder Instrument Co., 2293 N. Clybourne Ave., Chicago 14, Ill.

Tantalum sheet and foil (mill and stock) prices are listed in 6-p Price List 2.602-1.—Fansteel Metallurgical Corp., North Chicago, Ill.

Film-badge services offered are described in 8-p pamphlet.—Controls for Radiation, Inc., 130 Alewife Brook Pkwy, Cambridge 40, Mass.

Sample-counting equipment selection is subject of Bulletin 89 that places particular emphasis on choice of detector, its shielding and sample positioner or changing mechanisms.—Tracerlab Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Glove boxes, fume hoods, radioactive-waste containers, etc. are described in 12-p folder.—S. Blickman, Inc., 8400 Gregory Ave., Weehawken, N. J.

"Industrial pH Equipment" is title of 8-p Bulletin 5400.—Process Instruments Div., Beckman Instruments, Inc., 2500 Fullerton Rd., Fullerton, Calif.

Refractory materials (ZrO_2, BeO, MgO, ThO_2, etc.) are listed in technical data sheets.—Zirconium Corp. of America, Solon, Ohio

NUCLEAR CAMPUS

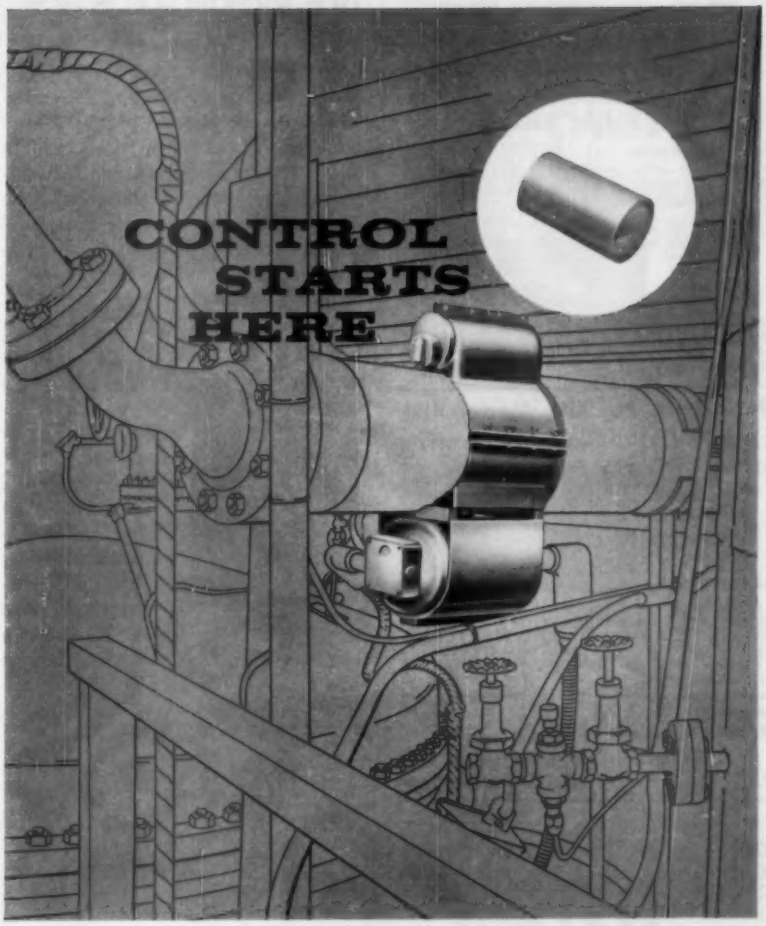
• **New Nuclear Training Facilities. Univ. of Arizona,** Tucson, will install a 10,000-watt, $160,000, multipurpose reactor this summer—purchased from General Atomic division, General Dynamics. . . . **Georgia Institute of Technology** has broken ground for its $600,000 radioisotopes and bioengineering lab to house a subcritical assembly and Van de Graaff accelerator; completion is scheduled in spring of 1959. . . . **Washington State College** expects to complete its research reactor building in August; a swimming pool unit will be installed early next year. . . . AEC has invited proposals to build **Puerto Rico's** projected nuclear research center at Mayaguez; bids were due June 5. . . . **Texas A & M** has hired General Dynamics' Convair division to develop plans for expansion of A & M's nuclear facilities; $675,000 has been allocated for preliminary expenses of a nuclear science center and building will begin when the Convair study is finished. . . . **The Air Force Institute,** Wright-Patterson Air Base, has installed a natural-uranium, light-water-moderated subcritical assembly; a pulsed neutron source will be installed to give the assembly greater versatility. . . . **Florida State Univ.** has ordered two linear accelerators from High Voltage Engineering—a 10-Mev tandem-type machine and a smaller 3-Mev unit. . . . **Univ. of Virginia** expects to complete its 100-kw swimming-pool reactor late this year; it is being built with the aid of industry contributions valued at $200,000, one-fifth total cost.

Courses

Principles of Radioisotope Utilization, a special summer course, is being offered by Massachusetts Institute of Technology July 14–25.

Nuclear Rocket Theory is being offered by Atomics International to the engineers of its sister division of North American Aviation—Rocketdyne. The course is given in 26 sessions, twice each week for a 3-month period.

Scientific Russian, a course designed for graduate engineers and scientists, will be offered June 16–August 9 by Carnegie Institute of Technology. Stress will be on a quick acquisition of reading knowledge in technical literature.



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Beta sources utilizing H^3, C^{14}, Ni^{63}, Pm^{147}, Tl^{204}, Kr^{85}, Sr^{90} and other beta-emitters are offered in various intensities and design parameters. Neutron sources, calibrated or uncalibrated, can be obtained from USR in radium-beryllium, radium D-beryllium, polonium-beryllium and actinium-beryllium. Light sources, for marking and signalling, are now available with H^3, C^{14}, Kr^{85}, Sr^{90}, Pm^{147}, Tl^{204} isotopes.

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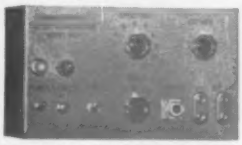

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NEWSMAKERS

Robert Paxton, executive vice president, operations, at General Electric, is GE's new president. With the company since 1923 and a vice president since 1950, he succeeds **Ralph J. Cordiner,** who moved up to chairman of the board. Paxton now becomes responsible for managing all of GE's operations components.

Bruce R. Prentice has been named manager of nuclear applications (Europe) for GE's atomic power equipment dept., a new post in the firm. Prentice will establish his headquarters in Switzerland, responsible for sale of APED products and services on the Continent with emphasis on power reactors. Prentice was formerly manager of nuclear systems design study for APED.

Prentice

Two new changes at AEC's Hanford Works: **H. H. Schipper** will fill a new post—assistant manager for technical operations; his former post—director of construction, engineering and supply—has been assumed by **D. J. O'Neil.**

Zirconium Corp. of America has a new technical director—**Paul Yavorsky,** former chief ceramic engineer at McDaniel Refractory Porcelain Co.

John T. Bailey has been named chief design engineer, Vitro Engineering div. of Vitro Corp. of America. The appointment marked his tenth year with the firm; among his responsibilities since 1948 have been design-construction of the Armament Center, Eglin Air Force Base, and design of launching facilities for the Army's Hawk missile.

Bailey

Guy Suits, GE vice president and research director, has been elected a director of the Industrial Research Institute.

One of Britain's leading young engineers, **H. H. Gott,** has been named nuclear plant design engineer, Central Electricity Generating Board. Gott was formerly chief engineer for reactor design, industrial power branch, Atomic Energy Authority.

AEC's engineering development branch has a new section chief—**Francis E. O'Meara,** head of reactor engineering and formerly a staff member of the weapons system evaluation group at the Pentagon.

William S. Gallaway has been appointed senior physicist, Beckman Instruments' scientific div., where he will direct exploratory research into advanced types of analytical instrumentation.

W. A. Pulver has been appointed chief engineer, Georgia div. of Lockheed Aircraft, succeeding **R. W. Middlewood.** The latter has taken on the directorship of Lockheed's new Georgia Nuclear Laboratories.

Westinghouse has helped **John W. Simpson,** manager of the Bettis atomic power div., to celebrate his twentieth year with the company by promoting him to a vice presidency. Under Simpson's direction, Bettis has developed the reactors for Shippingport and the naval submarine program and is working on reactor development for cruisers and aircraft carriers.

Simpson

Fred L. Niemann has been named physicist in technical sales, High Voltage Engineering Corp. Niemann's past associations have been with Hycon Eastern, MIT's Lincoln and Radiation laboratories, Harvard's nuclear laboratories, and the Office of Naval Research.

Nine Argonne National Laboratory scientists have been raised to the rank of senior scientist: **Paul R. Fields, Lawrence E. Glendenin, Gerhart R. Hennig, John R. Huizenga, Bernard Smaller, Ellis P. Steinberg, Robert J. Thorn** and **Philip H. Yuster,** all of chemistry div., and **Martyn H. Foss,** particle accelerator div.

New members of the atomic energy div., Phillips Petroleum, are: **Kirby S.**

Dawson and **John P. O'Neil,** reactor engineers; **John Waage,** research engineer, reactor physics and engineering branch; **Norwood V. Fridal,** health physicist, Materials Testing Reactor; **Douglas W. Divine,** reactor computations mathematician; and **Michael G. Blitch,** reactor physicist.

Stone & Webster Engineering Corp. has created an industrial projects div. and selected **Elliot F. Jaquith** to head the unit as chief engineer. Jaquith was formerly engineering manager, London office, for Stone & Webster's British subsidiary, E. B. Badger & Sons. He handled Badger projects in the U. K., Europe and Middle East.

Jaquith

W. Harrison Faulkner, Jr., a 10-year man with Tracerlab, has been elected vice president for engineering and development.

Horace A. Howe has joined the staff, Naval Radiological Defense Laboratory, as head of the accelerator branch, nucleonics div. Other new staffers are: **Moris L. Shore,** biophysics branch; and **Hans Weltin,** on temporary assignment until this fall, when he becomes head of the physics dept. at Robert College, Istanbul, Turkey.

American Machine & Foundry's atomic energy div., putting new emphasis on foreign operations, has picked **Nicholas Ovuka,** a 14-year veteran in atomic energy, to handle liaison with AEC, other government agencies, private firms and representatives of foreign countries interested in atomic energy. His career includes service with the Manhattan project, AEC and Babcock & Wilcox.

Ovuka

Two research posts have been filled by Corning Glass—**William W. Shaver** has taken over the fundamental physical research dept., succeeding **Howard R. Lillie.** Lillie has moved up to a new post—staff research manager; Shaver will continue his atomic energy research in his new job.

Henry G. Petrow has left National Lead Co. to join Ionics, Inc., as senior research chemist. At National Lead he was chemical research director in the AEC-owned Raw Materials Development Laboratory, Winchester, Mass.

H. Frederick Hamann has been appointed patent counsel for the Nuclear Products-Erco div., ACF Industries, after four-and-a-half years as a patent attorney at Los Alamos Scientific Laboratory.

The former assistant director and chief engineer at the Univ. of California Radiation Laboratory, Livermore, has established a firm under his name—**William M. Brobeck & Associates,** Oakland. Brobeck served as a member of AEC's national steering committee for the controlled fusion program, 1954–57.

A major post at Atomics International has been filled by **Clement F. Burnap,** a technical salesman stressing licensing activities in the marketing of reactors abroad. Burnap is former sales manager, foreign operations, at Reynolds International, and has had extensive experience in establishing heavy chemical and power plants in foreign countries.

Burnap

Paul F. Sweifel has been named associate professor of nuclear engineering, Univ. of Michigan, for a two-year period beginning this fall. Sweifel is a member of the AEC advisory committee on reactor physics.

Rudolf P. Nissen is a new staff member of the accelerator development dept., Brookhaven National Laboratory.

Alco Products has moved two of its executives to the top positions: **Perry T. Egbert,** president, to board chairman; and **William S. Morris,** executive vice president, to president.

Four men have joined Nuclear Corp. of America: **Milton M. Waller,** vice president; **David G. Keller,** personnel director; **James H. Hutton,** advisory engineer; and **Donald S. Kellogg,** consulting engineer. Hutton was manager of programs for Bell Aircraft's former nucleonics dept.

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NUCLEAR CALENDAR

June 15–19—Semiannual Meeting of American Society of Mechanical Engineers, Detroit (*Statler*). Contact ASME, 29 West 39th St., New York 18, N. Y.

June 16–20—Fifth Annual Meeting, International Congress on Electronics and Atomic Energy, Rome. Concurrent exhibition on peaceful uses of atom will run through June 30.

June 19–21—5th annual meeting, Society of Nuclear Medicine, Los Angeles. Contact G. C. Kyker, ORINS Medical Div., Box 117, Oak Ridge, Tenn.

June 23–27—1958 Gordon Research Conference on Nuclear Chemistry, Meriden, N. H. (*Kimball Union Academy*). Talks on nuclear spectroscopy, photonuclear reactions, heavy ion reactions, hot atom chemistry, chemical techniques. Contact W. George Parks, U. of Rhode Island, Kingston.

June 24—Third Annual Symposium on Radiation Effects, Boston (*Statler*), sponsored by American Society for Testing Materials and Atomic Industrial Forum. Papers on dosimetry, new irradiation facilities, and irradiation studies on organics, metals and ceramics. Contact J. H. Kittel, Argonne National Laboratory, Lemont, Ill., or A. N. Tschaeche, Sandia Corp., Albuquerque.

Aug. 10–16—International Congress of Radiation Research, Burlington, Vt. Contact John S. Coleman, 2101 Constitution Ave., Washington 25, D. C.

Sept. 1–13—Second International Conference on Peaceful Uses of Atomic Energy, Geneva, sponsored by United Nations. Contact Sigvard Eklund, United Nations, N. Y.

Sept. 15–19—International Instrument-Automation Conference, Philadelphia (*Convention Hall*), sponsored by the Instrument Society of America. Program includes two technical sessions on nuclear instruments. Contact Fred J. Tabery, 3443 S. Hill St., Los Angeles.

Sept. 16–20—International Symposium on Nuclear Electronics, Paris (*UNESCO House*). Contact Colloque International Electronique Nucleaire, 10 Avenue Pierre-Larousse, Malakoff (Seine), France.

Oct. 15–17—Second Energy Resources Conference, Denver (*Brown Palace*). General theme is "energy and its impact on society"; also discussion of the world's oceans as an energy source. Speakers include Warren Johnson, Univ. of Chicago, reporting on the Geneva conference. Contact Denver Chamber of Commerce.

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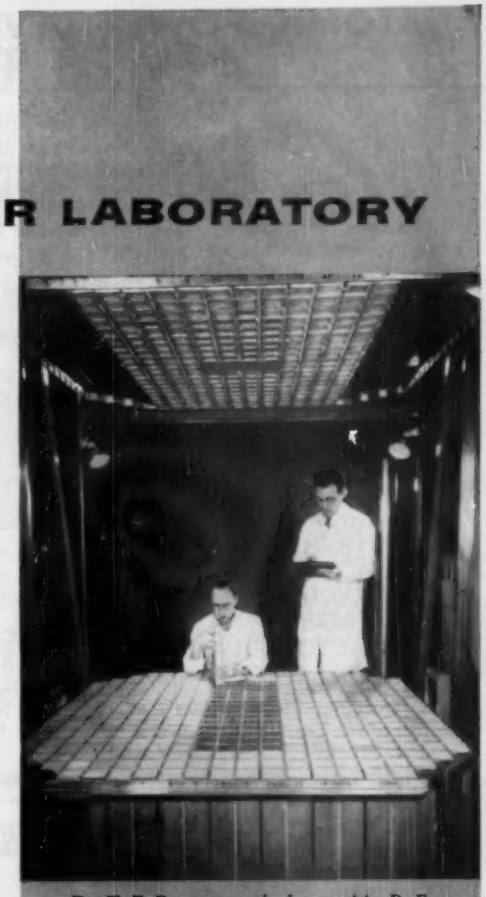

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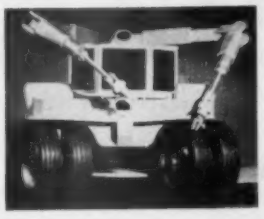

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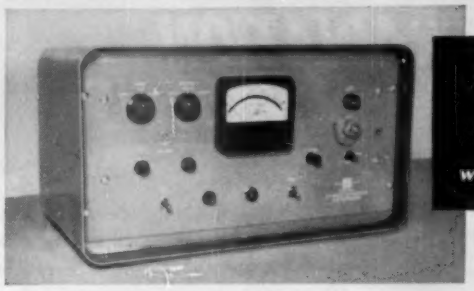

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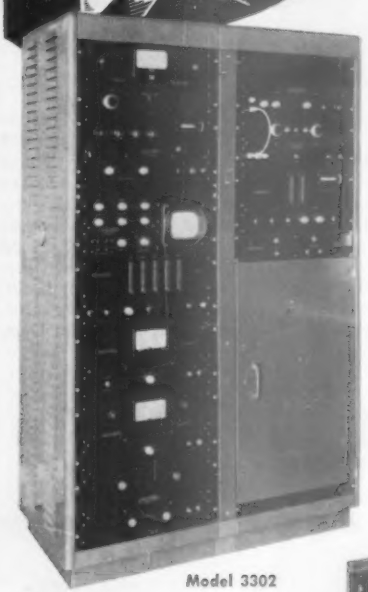

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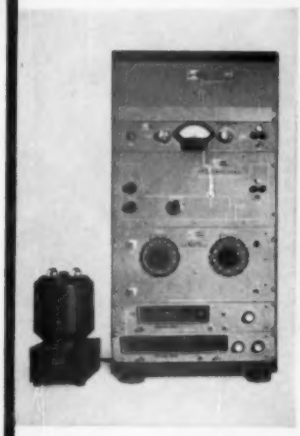

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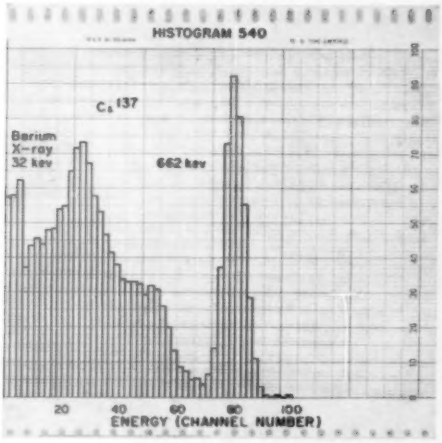

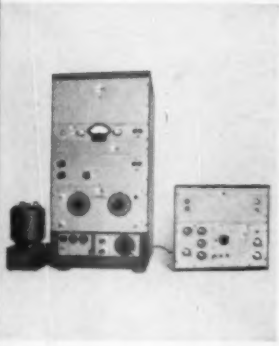

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IN AUTOMATIC RECORDING SPECTROMETRY

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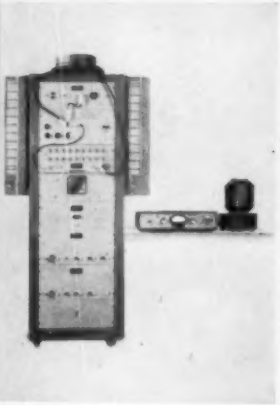

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IN HIGH SPEED MULTICHANNEL DIFFERENTIAL SPECTROMETRY

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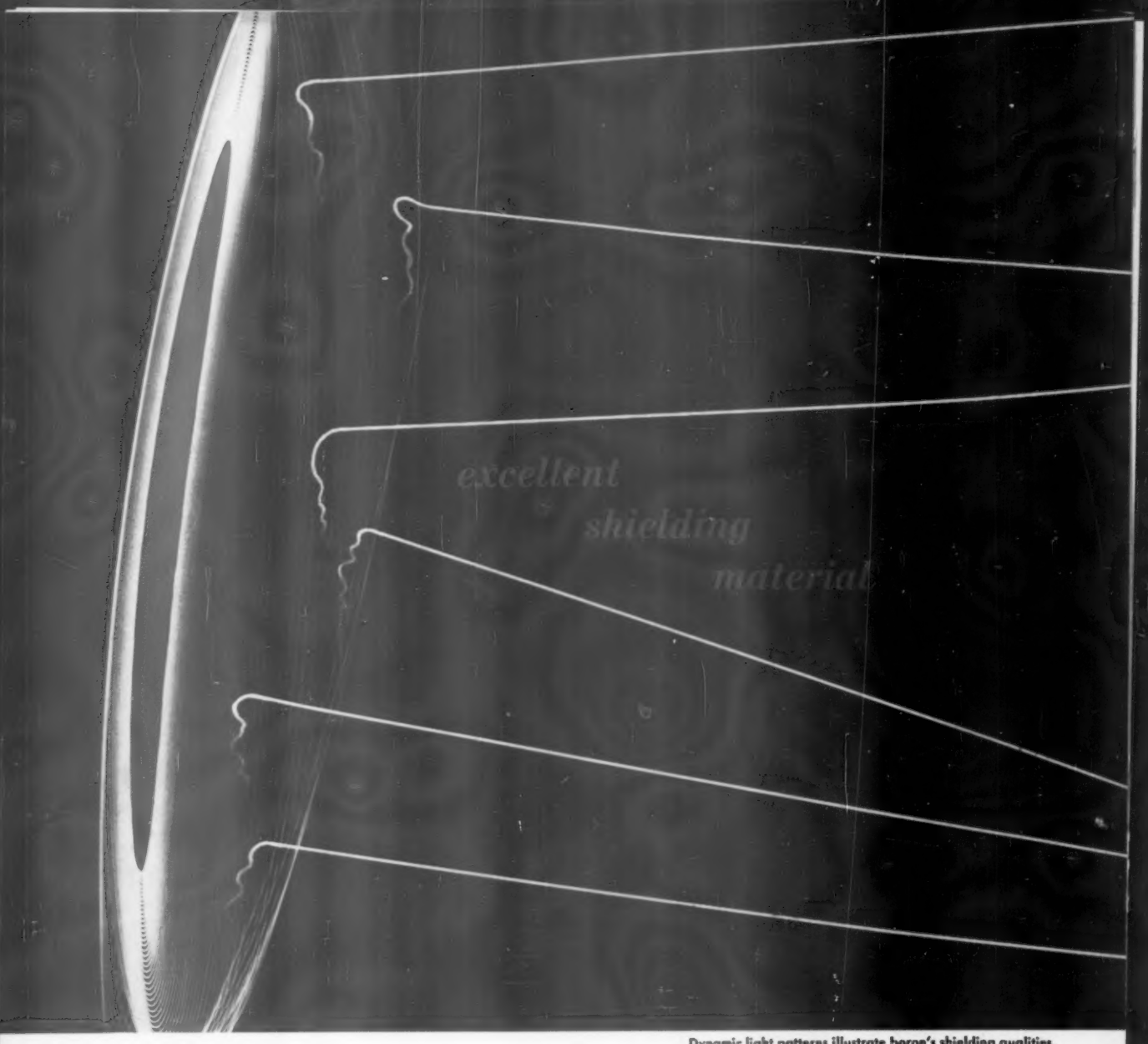

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